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Abstract: In 2006 the USGS began funding multi-institutional, collaborative research to begin the process of testing earthquake early warning (EEW) algorithms on real-time seismic networks within the ANSS. The result is the prototype ShakeAlert system that has been operating since 2012. Scientific, technical and societal advances on this project have been possible as a result of the close collaboration of our universities and the USGS. During this funding period, ShakeAlert shifted from being a prototype system to being a fully functional, West Coast-wide public system. This monumental accomplishment was made possible through the close collaboration of our universities and the USGS, and is one of the most significant advances that the US seismology community has made. As with the previous funding period, activities during this project interval were divided into two tasks. The first task is the operation, maintenance, and improvement of the data processing and the algorithms that contribute to ShakeAlert, as well as to continue to engage with users. The second is to continue to improve the seismic and geodetic infrastructure along the West Coast to provide faster and more robust alerts.

Highlights of Task I activities from the past two years include the following: Improving coordination of all aspects of the project at all levels of effort; continuing to develop and improve ShakeAlert algorithms to improve performance and reliability; improving and codifying the cross-institutional collaboration and coordination associated with the development and implementation of new elements for ShakeAlert; working towards the integration of GNSS algorithms; ongoing cross-institutional system maintenance, monitoring, and performance evaluation; and continuing to actively engage with users to ensure adoption, and develop a coordinated education and communication plan for all ShakeAlert partners. As Task II activities revolve around network maintenance and expansion, they can be summarized by the number of new or upgraded stations now contributing seismic data to ShakeAlert. Over the past two years, 228 stations have been installed or upgraded by project participants or other collaborators and are now contributing to EEW. Additional stations are in the vetting process or will be installed and brought online in the next few years. The Task II activities were funded by the USGS as well as the West Coast states, and include improvements to seismic stations made by partner networks such as the California Geological Survey, the University of Nevada Reno, and others.

Project data: Waveform data and metadata for stations used in this project are available through the data centers operated by the Incorporated Research Institutions in Seismology (IRIS; www.iris.edu), the Northern California Earthquake Data Center (NCEDC; http://ncedc.org) and the Southern California Earthquake Data Center (SCEDC, https://scedc.caltech.edu/). ShakeAlert position timeseries data from the BK, CI, NC, PB, PW networks are available in real-time via the Earthworm GPS_RING on all EEW development nodes. These data are also available via FTP in miniSEED format from the NCEDC archive (ftp://ncedc.org/gps/rt/). There are regular updates to metadata available by FTP (ftp://ncedc.org/outgoing/gps/ShakeAlert/metadata/) and on development nodes under /app/share/etc/geodetic. Data quality and flow have been continually improved upon by the various data providers.

Bibliography of all publications resulting from the work performed under the award:

Böse, M., J.R. Andrews, J. Li, S. Julien-Laferrière, F. Massin, A. Hutchison and J.F. Clinton (2020), The Finite-Fault Rupture Detector (FinDer): Recent Performance and Developments, iPoster presented at 2020 AGU Fall Meeting, 1-17 Dec.

Böse, M., J. Andrews, R. Hartog, and C. Felizardo (in prep). US West Coast ShakeAlert Warning System: Development and Performance of Finite-Fault Rupture Detector (FinDer) v.3. *In prep.*

Chung, A.I., M.-A. Meier, J. Andrews, M. Böse, B.W. Crowell, J.J. McGuire, and D.E. Smith (2020). ShakeAlert Earthquake Early Warning system performance during the 2019 Ridgecrest earthquake sequence. *Bull. Seism. Soc. Am., 110 (4).*

Crowell, B.W., et al, Enhanced performance of ShakeAlert using geodetic algorithms: The 2019 Mw 7.1 Ridgecrest, California Earthquake.
https://docs.google.com/document/d/1wGr8_NhRR9ju8d4DJfSA8rkP72QtUoh9MLQWC35Uk0A/edit?usp=sharing

Kohler, M.D., D.E. Smith, J. Andrews, A.I. Chung, R. Hartog, I. Henson, D.D. Given, R. de Groot, and S. Guiwits (2020). Earthquake Early Warning ShakeAlert 2.0: Public rollout. *Seism. Res. Lett., 91 (3).*

Meier, M.-A., Z.E. Ross, A. Ramachandran, A. Balakrishna, S. Nair, P. Kundzicz, Z. Li, J. Andrews, E. Hauksson and Y. Yue (2019). Reliable Real-Time Seismic Signal/Noise Discrimination With Machine Learning. *J. Geophys. Res. Solid Earth, Jan 2019, 10.1029/2018jb016661.*

Meier, M.-A., Kodera, Y., Böse, M., Chung, A., Hoshiba, M., Cochran, E., et al. (2020). How often can Earthquake Early Warning systems alert sites with high-intensity ground motion?. *J. Geophys. Res.: Solid Earth, 125, e2019JB017718. https://doi.org/ 10.1029/2019JB017718*.

Stubailo, Igor and Alvarez, Mark and Biasi, Glenn and Bhadha, Rayomand and Hauksson, Egill (2021) Latency of Waveform Data Delivery from the Southern California Seismic Network during the 2019 Ridgecrest Earthquake Sequence and Its Effect on ShakeAlert. Seismological Research Letters, 92 (1). pp. 170-186. ISSN 0895-0695.

Thompson, Mika, J. R. Hartog, E. A. Wirth (2021). Effect of fixing earthquake depth in ShakeAlert algorithms on performance for intraslab earthquakes. *Seism. Res. Lett.*, **92** *(6)* https://doi.org/10.1785/0220210056.

Goal 1.1: Coordination and Management

Richard Allen (UCB) ExCom EEW Science Forum Science R&D Alerting Strategies WG	Mario Aranha (UCB) GATIS WG Geodetic Data WG GFAST PGD WG	Angela Chung (UCB) EEW Science Forum (Chair) Alerting Strategies WG Complex Sequences WG GATIS WG SA Magnitude Saturation WG Science R&D Software Management WG System Performance WG	Tal Edgecomb (UCB) EEW Science Forum Technical User WG
Peggy Hellweg (UCB) ExCom EEW Science Forum RSN Managers WG California EEW System Operations WG	Ivan Henson (UCB) AQMS SWG SVN-to-GIT Production WG SA Magnitude Saturation WG Software Management WG	Julien Marty (UCB) ExCom JCCEO Community RSN Managers WG	Brian Pardini (UCB) DevOps WG Production WG ShakeAlert IT Security WG
Jennifer Strauss (UCB) California State Committee WG EEW Science Forum External Affairs WG JCCEO Technical User WG Legislative Affairs WG GitLab Project (Co-chair)	Fabia Terra (UCB) EEW Science Forum GMM WG REI (Chair) RSN Managers WG Strong Motion WG	Stephen Thompson (UCB) Production WG	
Jen Andrews (CIT) Alert Optimization WG EEW Science Forum GMM WG SA Magnitude Saturation WG Software Management WG System Performance WG	Rayo Bhadha (CIT) Production WG Software Management WG	Claude Felizardo (CIT) Production WG Software Management WG	Egill Hauksson (CIT) ExCom EEW Science Forum RSN Managers WG Science R&D
Allen Husker (CIT) ExCom EEW Science Forum Science R&D	Tom Heaton (CIT) ExCom EEW Science Forum GMM WG Science R&D	Elijah Marchese (CIT) Software Management WG	Men-Andrin Meier (CIT) EEW Science Forum System Performance WG

Becky Roh (CIT) EEW Science Forum GMM WG	Margaret Vinci (CIT) JCCEO TUWG ShakeAlert Messaging Toolkit FG		
Doug Toomey (UO) ExCom EEW Science Forum	Leland O'Driscoll (UO) RSN Managers WG Telemetry WG	Lucy Walsh (UO) TUWG (Co-chair) Community Resources WG ORCCEO chair WACCEO ShakeAlert Messaging Toolkit FG	Gillean Arnoux (UO) OR array buildout Data Operations
Paul Bodin (UW) ExCom EEW Science Forum RSN Managers WG	Brendan Crowell (UW) EEW Science Forum GATIS (Chair) GMM WG Science R&D System Performance WG	Renate Hartog (UW) Alert Optimization WG EEW Science Forum GMM WG Production WG SA Magnitude Saturation WG (Co-chair) Software Management WG (Chair) Timed Data Playback	Alex Hutko (UW) EEW Science Forum Production Regional Coordinators
Victor Kress (UW) Active MQ configuration WG Common Event IDs WG GATIS GNSS data Production WG Software Management WG	Gabriel Lotto (UW) Educational Resources WG GitLab Project (Co-chair) TUWG ORCCEO WACCEO ShakeAlert Messaging Toolkit FG (Chair)	Mouse Reusch (UW) Community Resources WG (Co-chair) Educational Resources WG EEW Science Forum External Affairs WG JCCEO Production WG TUWG REI WG	Bill Steele (UW) Educational Resources WG JCCEO TUWG Washington State CEO Committee (Co-chair) ShakeAlert Sector Symposiums focusing on Critical infrastructure and Lifeline managers
Harold Tobin (UW) ExCom EEW Science Forum Science R&D	Carl Ulberg (UW) EEW Science Forum Software Management WG		

Table 1.1.1. University involvement in ShakeAlert groups. Yellow: UCB; orange: CIT; blue: UO; green: UW.

Goal 1.2: Integrating algorithms and ongoing improvements

Milestone 1.2.1: EPIC Improvements

Items completed

- During the first year, Chung (UCB), with support from Meier (CIT), explored the feasibility of implementing the machine learning signal/noise classifier developed by Meier et al. (2019) into the EPIC algorithm to reduce the number of spurious triggers coming into the system. Since then, Chung and Henson (UCB) have developed both offline and real-time methods to test the classifier. The performance of the classifier has been tested on three separate datasets:
    a) A dataset comprised of earthquake and noise signals from NCEDC and SCEDC (Figure 1.2.1.1).
    b) The STEAD dataset (Mousavi et al., 2019).
    c) Earthquakes from the T&C testsuite.

  These tests were used to identify and address weak spots in the existing models, and to identify strategies to further improve the reliability and robustness of the models. Overall, the classifier and preliminary modified EPIC code are working well. The classifier appears to correctly classify most impulsive signals as noise and most earthquake signals as earthquakes. The team has evaluated the performance of the model on individual waveforms using the scikitlearn module (datasets a and b), and also explored how the classifier can be implemented using a preliminary modified version of EPIC that incorporates the classifier (dataset c).

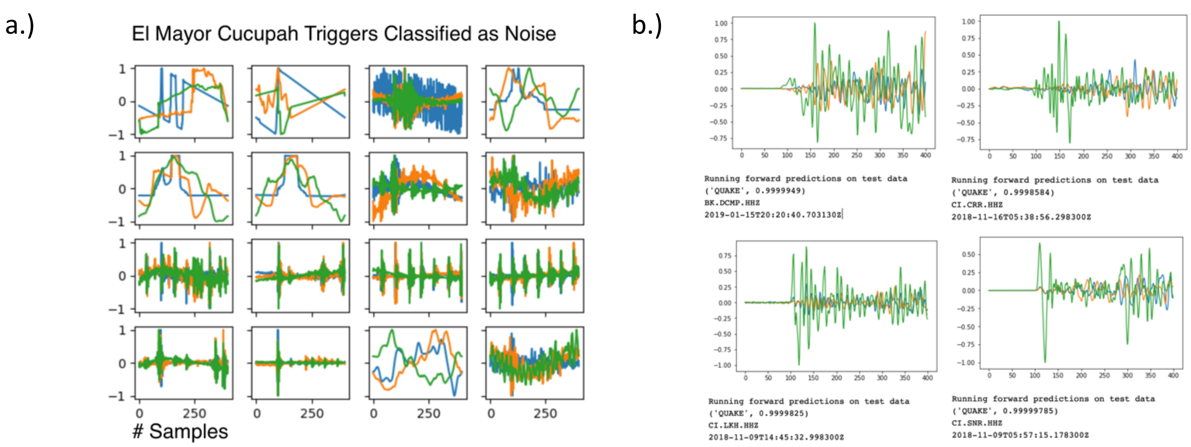

***Figure 1.2.1.1**. a.) Example triggers from modified EPIC replays of the El Mayor Cucupah T&C testsuite earthquake that were classified as noise. This is the correct classification of these signals. b.) Examples of correctly classified earthquake signals from Northern California and Southern California stations.*

Using an adapted DM Review Tool, UCB is now monitoring a real-time modified version of EPIC with the classifier to understand its performance and what modifications may need to be made to the model and/or logic. This new tool will be crucial for evaluating the performance of the new versions of EPIC (Figure 1.2.1.2)

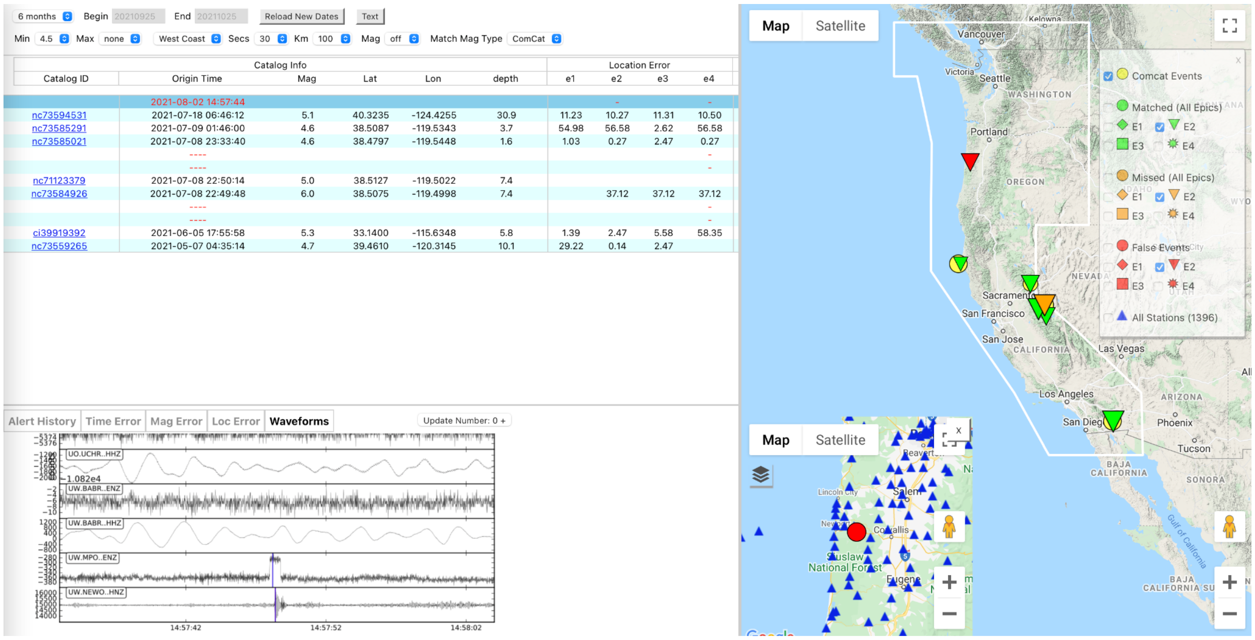

Figure 1.2.1.2. *Screenshot of the new EPIC Review Tool, which allows for the comparison of up to four versions of EPIC at a time.*

- The Ridgecrest earthquake sequence provided an exceptional dataset for the ShakeAlert team to understand how EPIC performs during an intense sequence of earthquakes. This dataset has been and will continue to be invaluable as we make improvements to and test the algorithm.
- Though the original proposal did not have a plan for modifying the way that EPIC calculates magnitude estimates, the Ridgecrest earthquakes made it clear that a change had to be made to improve performance during larger earthquakes. At the time of the Ridgecrest earthquakes, EPIC averaged magnitude estimates from all reporting stations equally. Of the four stations to send an initial magnitude estimate for the mainshock, one had a very low estimate of M4.1 as there was not much data available at that station at the time. This pulled down the overall magnitude estimate. In order to avoid this problem in the future, Chung and Henson (both UCB) made a modification to EPIC so that it now weights the magnitude estimates from individual stations by how much data is available at that station. With this modification, initial estimates may be more accurate, particularly for larger earthquakes (Figure 1.2.1.3; Table 1.2.1.1). The ExCom decided to delay implementing this modification until after recommendations from the Alerting Strategies working group have been implemented in order to prevent possible erroneous over-alerting.

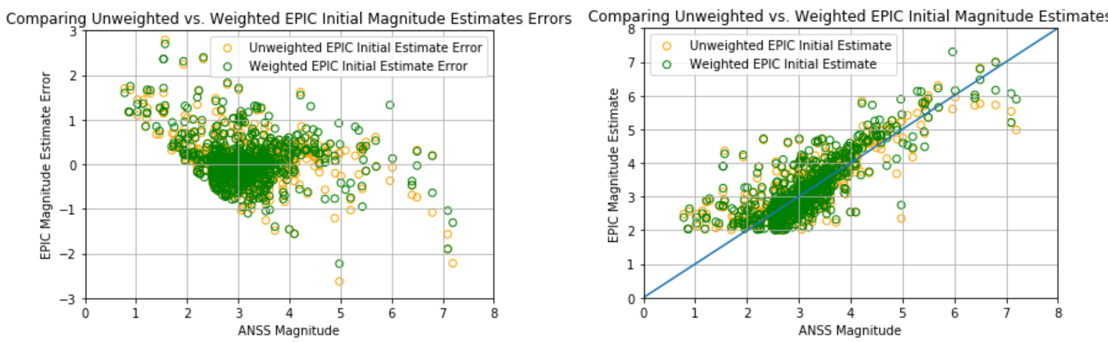

Figure 1.2.1.3*. Comparing Unweighted (orange) vs. Weighted (green) estimates using a dataset comprised of the T&C Testsuite, 238 M3.0+ earthquakes during the period 2019-07-04 – 2019-07-07 (during the Ridgecrest sequence), and 487 earthquakes for which EPIC created at least M2.0+ alerts during the period 2016-02-16 – 2017-10-31. Left plot compares magnitude estimates, right plot compares magnitude estimate errors.*

Event	lat	lon	ANSSmag	time	unweighted mag	weightedmag
Napa	38.2155	-122.31167	6.02	2014-08-24T10:20:44.06	5.95	6.15
Vancouver	49.535	-126.893	6.4	2011-09-09T19:41:34.15	5.93	5.93
RidgecrestM6	35.7052	-117.506	6.4	2019-07-04T17:33:49.04	5.71	6.02
San Simeon	35.7005	-121.1005	6.5	2003-12-22T19:15:56.24	6.82	6.79
Off-Ferndale	40.652	-124.6925	6.5	2010-01-10T00:27:39.32	5.76	6.47
Nisqually	47.149	-122.727	6.8	2001-02-28T18:54:32.00	7	6.99
Off-Eureka	40.829	-125.13383	6.8	2014-03-10T05:18:13.43	5.72	6.16
Hector Mine	34.594	-116.271	7.1	1999-10-16T09:46:44.13	5.2	5.2
RidgecrestM7	35.7695	-117.59933	7.1	2019-07-06T03:19:53.04	5.53	6.06
El Mayor	32.2862	-115.2953	7.2	2010-04-04T22:40:42.36	4.98	5.89

Table 1.2.1.1*. Performance of revised weighting scheme ("Weighted Mag") vs original magnitude averaging ("Unweighted Mag") for the M6+ earthquakes in our dataset. Highlighted cells show better performing version of the algorithms (magnitude estimate closest to ANSS magnitude).*

- (UCB) Evaluated EPIC's performance during out-of-network events, which helped illuminate weaknesses in the algorithm.
- (UCB) Test performance in intense sequences. Participated in a short-term working group to assemble synthetic data sets of complex sequences (foreshock/mainshock and mainshock/aftershock), to understand current system behavior and suggest future developments. UCB contributions were analyzing and interpreting results of replays.

Milestone 1.2.2: FinDer improvements

FinDer developments are carried out in a collaborative effort between Andrews (CIT), Böse (ETH), and Hartog (UW). Caltech contributions for the work described below include all modifications to the C++ code, deployment to dev systems and deployment requests, and some testing and analysis work.

Items completed

- (CIT, ETH) Improved handling of real-time data latencies. Changes for latent data handling resulted in increasing the maximum magnitude estimated, as well as reducing the time taken for magnitude estimates to increase. The updated code version was deployed for production in March 2020.
- (CIT, ETH) Faster prediction of final magnitude. Changes were made to PGA threshold selection. This approach was found to reduce time to peak magnitude estimates by approximately 10s for the Japanese Kumamoto event and the M7.1 Ridgecrest mainshock. The updated code version was deployed for production in December 2020.
- (CIT, ETH) Test performance in intense sequences. Participated in a short-term working group to assemble synthetic data sets of complex sequences (foreshock/mainshock and mainshock/aftershock), to understand current system behavior and suggest future developments. Caltech contributions were in final formatting and configuration of test data sets, running test data sets through the whole algorithm stack, creating analysis scripts and computing ground motion outputs. Suggested future FinDer developments are for multiple event handling (currently code is unable to process more than one event at a time), and develop logic for separating alerts for events close in time but spatially distinct (currently the same event id is used).
- (CIT, UW) Optimize for earthquakes on the largest fault zones: CSZ and SAF. Significant code re-factoring and new code development has been completed:
    - Template sets can now be configured as either generic or fault-specific. Template parameters include the centroid polygon and magnitude range for which a template set should be tested.
    - Template matching has been adapted for either generic or fault-specific template sets, for the latter translation and rotation are disabled and ruptures and centroid locations are taken from input files.
    - Code for data image creation and template matching has been separated to allow creation of one data image and matching with multiple template sets. The latter has been multi-threaded to reduce processing time when multiple template sets are tested.
    - Template set selection logic is implemented based on version number, magnitude and epicentral location.
    - Logic is implemented to select the best rupture solution across different template sets.
    - Testing using trial SAF (M6.0-M8.3) and CSZ (M6.0-M8.9) fault-specific templates has been carried out, using both offline PGA files and synthetic waveform replays.
    - Testing using the STP 2.0 testing suite has been carried out, including using an extended generic template set for ruptures up to M9.
    - Real-time testing on the development systems has been in place for several months, and integration system testing should be imminent.
    - Re-factoring facilitated fixes for a memory leak, and image orientation error.
    - Unit tests have been created for a significant portion of the FinDer library and FFD codes.
    - Triggering and association functions were updated to reject more stations identified as noise.

  The code is in review, prior to being submitted to STP using an extended generic template set. Once fault-specific template sets are ready for deployment, configuration changes only will be required.

Synthetic broadband waveforms for scenario M9 Cascadia events (Wirth et al., 2018) and a M7.8 San Andreas event (Graves et al., 2011) have been used to assess performance. For all tests with synthetic data the new version of FinDer successfully utilizes multiple template matching, and Figure 1.2.2.1 shows examples of results using fault-specific templates. For the San Andreas event FinDer recovers a maximum magnitude of M7.7, for Cascadia scenarios, maximum recovered magnitudes vary between 7.8 and 8.9, and in all cases significant onshore shaking is successfully captured.

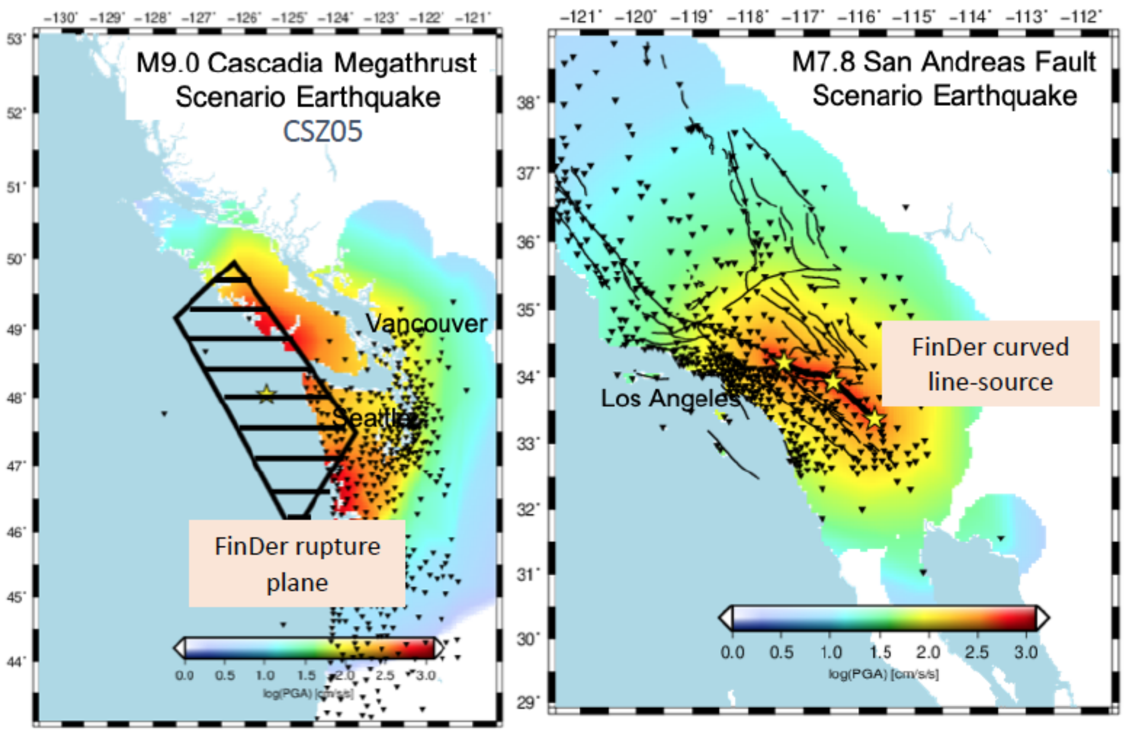

***Figure 1.2.2.1**. Examples of FinDer performance using fault-specific templates for (left) a Cascadia subduction zone scenario and (right) a southern San Andreas scenario. Map colors show the 'observed' PGA using the ShakeMap color scale (shown), yellow stars are marked along the fault rupture indicated by the hatched black polygon (left) or solid black line (right).*

Milestone 1.2.3: Station notification library

A basic station notification library within ShakeAlert is used to provide notifications for station status, which can be ingested by algorithms listening for the appropriate messages. This library required upgrades and rewriting to add security, modularity and flexibility.

Items completed

The following station notification library developments have been completed:

- (CIT) eewNotify AMQ broker: completed wiki documentation on broker setup to support activities at other centers. Modified eewNotify script to use SSL connections, and deployed to Caltech import servers.
- (CIT) StationNotification library: new library created, removing dependence on AQMS parsing code and CMS library for connecting Waveform Processing library to ActiveMQ.

- Library can be used by any application, not just those that use the Waveform Processing library used by EpicWP and FinDer-FFD2.
- Parsing of existing XML message is implemented using XercesC library which is already used by DM library, new status access functions and the use of an event listener pattern improve code structure.
- Library can use configuration file parameters or an existing connection for the ActiveMQ connection, increasing flexibility and optimizing connections. This will allow for the future use of SSL to secure communications and automatic failover provided by the ActiveMQ C++ library.
- New status access functions are called from within DataChannel.
- Comprehensive unit tests have been created for the new library.

The StationNotification library needs some further functionality, code review and STP submission. Old obsolete code will be removed, and functionality for static files (suspended/conditional) to use StationNotification API will be added. Existing applications using the original notification library will need to be updated to make use of some of the new features such as reusing an existing ActiveMQ connection instead of relying on the original library making a separate connection to the broker.

Milestone 1.2.4: Central Decision Module (CDM)

The solution aggregator (SA) within ShakeAlert v2.0 has responsibility for combining earthquake alerts from different algorithms, and currently merges core earthquake parameters (e.g. location, origin time and magnitude) using incoming likelihood estimates from the algorithms for weighting. The current method cannot meaningfully handle finite fault or ground motion information, making it insufficient as contributing algorithms evolve. The originally proposed modification to SA was to use the CDM (Minson et al., 2017). However during the initial design phase it was decided that a direct implementation would not be sufficiently general to allow all candidate algorithms (e.g. PLUM, GFAST) to optimally contribute. Several smaller steps have therefore been completed, that move ShakeAlert closer to the goal of ground-motion-based alerting.

Items completed

- (CIT) C++ modules to combine earthquake estimates in ground motion space have been converted into a library. Unit tests have been created using validation data computed externally.
- (CIT) A method to associate algorithm alerts using GM observations is in development and testing, since this should utilize parameters common to all algorithm alerts. This is demonstrated in Figure 1.2.4.1 for the M5.8 Petrolia event of March 9th 2020; in real-time the SA failed to associate the EPIC and FinDer alerts because of the significantly discrepant estimated epicenters, resulting in no alert being issued by the system even though ground shaking was felt onshore. However, there is spatial and temporal consistency in the instrument data used for alerts. This development is in a branch of the code repository, and will be ready for code review after final testing and optimization.

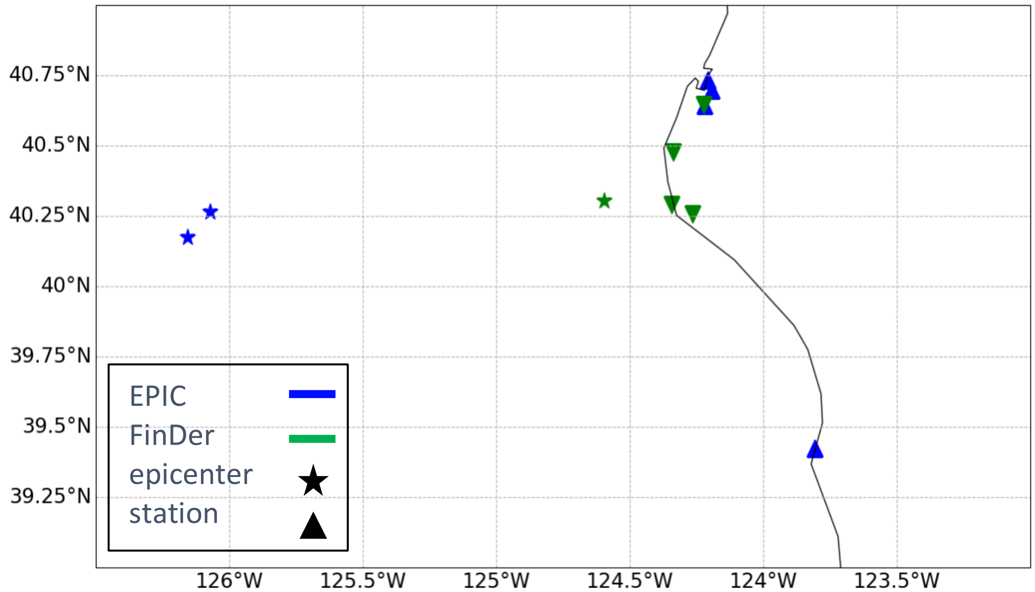

Figure 1.2.4.1. *Algorithm alert association for the M 5.8 Petrolia (offshore Northern California) earthquake of March 9th 2020. Stars show epicenters determined by EPIC (blue) and FinDer (green) and triangles show the stations used by each algorithm.*

Next planned steps to implement GM alert combination:

- Integrate ground motion map combination classes into current SA code as a configuration or compile option, as an alternative method for merge() function.
- Allow input/output of GM messages in SA (dmlib changes for rules relating orig_sys to message type).
- Compute GM for all algorithm messages.
- Compute all necessary outputs from new GMA.

Milestone 1.2.5: Integrating GNSS algorithms: G-FAST + GlarmS + BEFORES

Items completed – Algorithm Testing and Comparison:

- (UCB, UW) Continued to participate in GATIS testing, running replays of events including Napa, El Mayor Cucupah, Tohoku, and the M7.1 Ridgecrest earthquakes with the GlarmS (UCB) and GFAST (UW) algorithms.
- (UCB) Improvements made to the GlarmS offset estimator including post-event linear-weighted averaging with a 10s buffer and configuration changes to trigger on the S-wave instead of the P-wave arrival. In replay mode the timing of offsets and magnitude convergence closely matches that of GFAST. Other minor code improvements and bug fixes completed.
- (UCB) GlarmS replay results for Ridgecrest and other major historical events including ElMayor2010, Tohoku2011, Napa2014 are on ‘eew-bk-dev1’ under /home/mario/GATIS/.
- (UW) A full stack test suite system (seismic+geodetic tank files) was developed using code from T&C.
- (UW/UCB/UNAVCO) A test suite of 12 historical earthquakes has been vetted (USGS) and run through the full-stack of ShakeAlert. Analysis of results is ongoing.

Items completed – Algorithm Integration

- (UCB, UW) In mid-2020 there was some interest in including the Catalog Fault functionality of G-larmS into GFAST with UCB/UW/ISTI/NOAA initially working together so that this functionality would ultimately be in ShakeAlert. While this effort did not fully materialize, UW/ISTI are currently beginning to modify G-FAST to ingest a fault catalog and add additional G-larmS functionality with guidance from UCB. Modifications to the dmlib were made to prepare for gfast messages.
- (UW, UCB) GATIS group meetings were suspended from mid-December 2020 and replaced by the PGD group headed by Jessica Murray in order to assemble proper historical event datasets and work towards putting into production the GFAST-PGD algorithm for magnitude estimation.
- (UW) A noise analysis system was developed (using a database funded by a USGS external grant to BWC) to put real uncertainty bounds on the GFAST-PGD solutions. Logic to incorporate into the Solution Aggregator is ongoing.
- (UCB) Enabled distribution of real-time data/metadata so that GFAST-PGD can run in real-time on dev machines; also provided data archival and several event replay datasets.

Milestone 1.2.6: Augment testing datasets for algorithm replay

Items completed

- (UCB) Rather unexpectedly, the Ridgecrest earthquake sequence provided an exceptionally rigorous aftershock dataset on which to test current and future versions of ShakeAlert algorithms.
- (UCB, CIT) The recently created Complex Sequences Working Group has put together a dataset comprised of composite events in order to test the performance of all algorithms during complex seismic sequences.

PLUM Improvements (no milestone in proposal)

Items completed

- **(CIT) PRIDE: a novel wavefield-based EEW algorithm**
  We are developing a novel wavefield-based EEW algorithm that builds on the PLUM concept, and that exploits the way in which shaking intensities grow at near-epicentral sites (*Propagation of Radially Isotropic ground motion Decay, PRIDE*). Because, for large shallow crustal events, shaking intensities reach strong to extreme shaking intensities at near-epicentral sites in a matter of seconds, we can use these observations as clear, and sufficient, evidence that a large earthquake is underway, and to alert a large area around the sites that observe the shaking, using a generic maximum shaking intensity gradient. Our preliminary results suggest that, with this approach, we can alert a significantly higher fraction of affected sites and provide longer warning times than existing algorithms (Figure 1.2.6.1). More specifically, PRIDE can provide timely alerts in shallow crustal earthquakes for 85%, 50% and 20% of sites with strong, very strong and severe shaking intensities, respectively (Meier et al., in prep.).

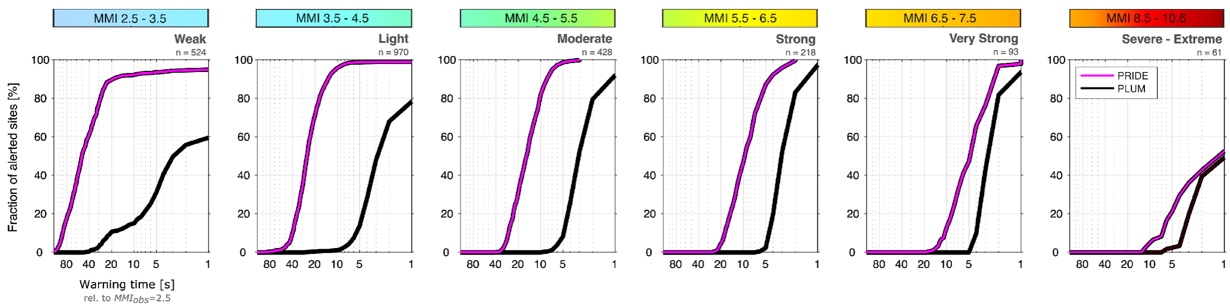

Figure 1.2.6.1: Cumulative distributions of gross warning times from the PRIDE (pink) and PLUM (black) algorithms for the 7 large shallow crustal earthquakes with M>=6.5. Here we evaluate all sites that should have been alerted (MMI_{obs} >= 2.5), and bin them with respect to their peak observed MMI. Reading example: Of all sites that had strong shaking (MMI 5.5 – 6.5), ~85% receive an alert from PRIDE with a gross warning time of >=5 s, and for ~45% of these sites gross warning times exceed 10 s.

Milestone 1.2.7: New offline algorithm evaluation framework (seismic and GNSS)

- This proposed effort was not funded.

Milestone 1.2.8: Class-C sensors: evaluating potential uses and requirements

- (UCB) MyShake has now been downloaded ~680,000 times in the states in which it delivers warnings (CA and OR). At the time of writing there are ~315,000 active users. When phones running MyShake are at rest, they monitor for earthquake-like motion and forward triggers to a central server when such motion is detected. Replays of real trigger arrivals for earthquakes that have occurred in the last two years demonstrate that 1) phones have reported earthquake motion up to a second earlier than traditional stations, and 2) combining MyShake triggers with traditional ones in EPIC could have sped alert creation by up to ~1/2 a second. Using a combination of trigger types also can net comparable accuracy in location estimates, relative to the traditional network alone. Results are best especially in urban areas where phone density is high, which are also the regions for which small improvements to alert speed matters most. Work is underway to assess how the acceleration information forwarded by phones could be used in magnitude estimations.

Goal 1.3: Ongoing cross-institutional system maintenance, monitoring and performance evaluation

Milestone 1.3.1: Ongoing algorithm performance review

Items completed

- (UCB) The new DM Review Tool is fully functional. This tool is invaluable for the ShakeAlert team when reviewing the systems’ performance. Several updates where also made to the DMReview page. A

MaxMag option was added to the web page. When this option is selected, the event information displayed is for the DM alert which had the largest magnitude. The information includes the alert-time, location and magnitude. The MaxMag values are also displayed in the Text page option. Two additional tabs were added to the webpage with information about the selected event. One of the new tabs includes compares the information from all machines. It has a table with the information about a single event as it was detected on each of the server machines. This table reveals any differences between the server machines. There is also a new IDs tab that displays the event ids for all of the algorithms (ANSS, DM, SA, Epic, and Finder) for the selected event. To provide for better backend service for the DM, Epic, StationMonitor web pages, a SpringBoot gateway server was added that forwards requests to separate backend servers for each of these pages. This configuration also allows for easier maintenance. The backend database access was changed to use the Spring Boot Database Pooling API, instead of direct database connections. This provides for more efficient and reliable database interactions.

- (UCB) The Station Monitor webpage code was revised to make it easier to add new stations.
- (CIT, UCB) In an effort to evaluate the potential and limitations of existing EEW algorithms we have performed a detailed comparison of the three algorithms currently most relevant for ShakeAlert: the EPIC point source algorithm, the FinDer seismic finite source algorithm and the PLUM wavefield based method (Meier et al., 2020). We have used a large data set of 85k strong motion records from Japan to replay the algorithms and to evaluate their performance both in an absolute and a relative sense (Figure 1.3.1.1). Among the main findings are that the algorithms can alert a significant fraction, but never all, of affected sites. For sites with low to medium shaking intensities, this fraction is close to 100%. For sites with strong to extreme intensities it is between 25%-50%. That is, existing EEW algorithms can potentially alert a significant fraction of even the hardest hit sites, albeit with short warning times of typically less than 10s. We are exploring ways to use similar analysis metrics with the STP team.

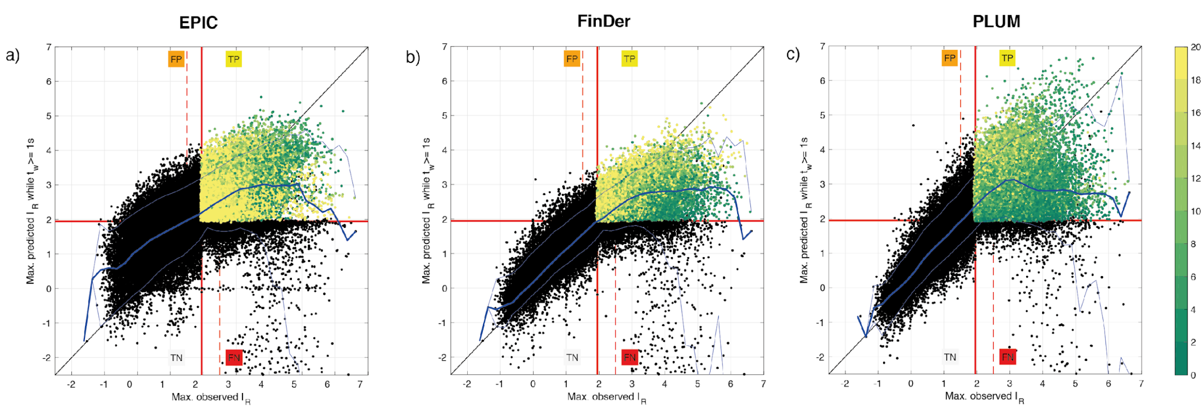

***Figure** 1.3.1.1: Predicted versus observed final peak shaking intensities (JMA instrumental intensity scale) from the EPIC (a), FinDer (b) and PLUM (c) algorithms. The predicted IR are the maximum predicted amplitudes while there was at least 1 s of warning time; that is, at least 1 s before the alerting threshold of IR' = 2.0 was actually exceeded.*

- (UW) To investigate whether an erroneous assumption of a shallow depth in the ShakeAlert algorithms EPIC and eqInfo2GM would significantly affect performance for deep intraslab earthquakes in terms of the predicted ground motions and warning times, UW graduate student Mika Thompson replayed data from intraslab events in Chile and the Pacific Northwest (PNW) through a test ShakeAlert system. Because intraslab events in the PNW occur below the dense parts of the PNSN network, when performance is measured as timely and accurate alerts based on the predicted MMI III, MMI IV, and MMI V contour, a shallow depth assumption for intraslab events in the Pacific Northwest will not significantly affect performance. See Thompson et al., 2021.

Milestone 1.3.2: Ongoing station performance, latency and data quality

Items completed

- (UCB, UW) UCB has developed a Station Monitor tool as part of the Decision Module review tool. It currently allows users to see station statistics such as 10 minute mean latency, 3 month mean latency, and the number of triggers over 10 min, 60 min, and 24 hours. UW has been developing tools that improve the capability for joint comparison of station metrics and network topology. The goal for these tools is to use the performance of individual stations and their locations relative to other stations in the network to rank channels and make decisions regarding maintenance visits and possible exclusion of data from noisy stations. UCB and UW coordinators and programming staff have met to develop a plan and pathway for the implementation of the improved Station Monitor tool, including new parameters and new visualization options.

Figure 1.3.2.1: *Screenshot of prototype "Squac" dashboard that queries the database of station/channel metrics. This view is of a collection of metrics/channel 10-minutes latencies of various sorts of importance in ShakeAlert algorithms. In this view, 98% of the packets have to have a latency of 3.5s or less to be labeled good in this dashboard (setting it to 5.0 changes it). red=bad,green=good, the other thresholds are: 0 spikes and 60s of high rms allowed (both are per hour). Gaps per hour <=1 is good, Completeness good: >= 98%. This is not the planned UI, but rather illustrates that the back-end and API are up and running.*

- (UCB) Fixed a problem with the Station Monitor web page for the rare cases that a station's data packets are received at two separate data centers. For example, data packets for a few of the NC stations are processed on both the eew-nc-prod1/2 machines and the eew-bk-prod1/2 machines. The packet latencies are significantly different on the nc and bk machines. The Station Monitor tool was corrected to display the station latencies from the machines where the latencies are the smallest, in this case the nc machines. Before this correction, the displayed latencies were not the smallest for all stations.

- (UCB) A miniSEED data archival system for GNSS position timeseries data was implemented in late 2019.
- (UCB, UW) Utilizing the archived miniSEED data and other tools, various QC metrics are under evaluation.

Milestone 1.3.3: Software maintenance (bug fixes and upgrades)

Items completed

- (UCB, UW) **SA/DM:** Options were added to allow more control of the algorithm magnitude weighting. A new Epic and Finder magnitude weighting scheme called MagWeightToggle was implemented. This new weighting scheme increases the weighting of Finder relative to Epic when the SA magnitude is above a threshold. Rounding of the magnitude in published XML messages, and consistent event IDs were implemented as well. A correction was also made to the initial implementation in the DM code that creates alerts for events outside of the alerting region, when the MMI-contour intersects the alerting region. Algorithm message definitions for gfast and plum were added to the dmlib in preparation for the inclusion of those two algorithms in ShakeAlert.
- (UCB) **EPIC:** A correction to the implementation of the parameter MaxMagDistkm was added. A bug was fixed that caused the trigger filter-bank measurement updates from the epicWP waveform processor to be ignored by the epic associator. The associator's internal trigger c++ map was modified to reduce the cpu time required to process triggers. This is a noticeable improvement of the processing of large events with aftershocks. An option was added to the Epic magnitude calculation process. The option is to weight the station Pdmag using the length of data available after the trigger at the time that the Pd amplitude measurement was made. A bug was fixed that caused the teleseismic filter update measurements to be ignored. A problem was fixed with the Epic magnitude computation when some contributing stations are more that 100 kilometers from the epicenter. Changes were made to Epic to facilitate the implementation of unit tests. These included some "cleanup" changes recommended by the unit test writer.
- (CIT) **eqInfo2GM**
    - The GMM WG recommended switching to a look-up table approach, rather than direct implementation of GMPEs, to allow faster adoption of updated relations and allow wider distribution of the data. The eqInfo2GM code has been modified to: have updated configuration options for look-up tables; use look-up tables for GMPE computations and determination of contour distance. We created the first set of look-up tables from the current eqInfo2GM code. Additionally, small improvements to the implementations of Worden et al. (2012) and Chiou & Youngs (2008) were made. Code changes and look-up tables were tested against ShakeMap, and these changes were deployed to production in December 2020.
    - Unit tests were developed for the majority of the eqInfo2GM library and application.
    - The GMM WG developed a new set of look-up tables created using NGA-W2 GMPEs and GMICEs, utilizing a different vs30 (350m/s) for the contour distances, and modified GMPE table resolutions to minimize uncertainty in ground motion when using the tables without interpolation. These tables were formatted, tested and submitted to STP in July 2021.
- (CIT) **Heartbeat Aggregator (HA):**
    - Updates have been made to validate configuration files, improve detection of internal system problems, and to report more consistently to external users and internal monitors. Wiki documentation has been expanded.

- (CIT) **UserDisplay (UD) and EEWDisplay:** Continued to track reported problems, creating issue tickets in GitLab.
    - Significant work has been carried out for the Fall 2021 release of EEWDisplay v2.8 to accommodate USGS-requested changes to use of trademarks and end-user license agreements. Most noticeably the program was renamed EEWDisplay instead of ShakeAlert UserDisplay and all graphics, icons and shortcuts have been updated. Additional changes and new features include:
        - Support for ShakeAlert's follow-up messages which are packaged slightly differently than original DM and eqInfo2GM messages and handling and display of "false" alerts.
        - Updated ShakeAlert license agreement and end-user manuals, plus ability to access the latest versions from the web.
        - Updated replay data using examples from the ShakeAlert scenario server.
        - Acknowledge feature to prevent EEWDisplay from grabbing focus.
        - Higher resolution map graphics.
        - Updated vs30 and cities files.
        - New Audio, Event Filter, and Visual settings.
        - Improved server connection behavior.
        - Easy setup for using Scenario Server.
        - Allow technical users to disable NTP synchronization if needed.
        - Allow user to set home location by clicking on map which has been a long time request.
        - Allow user to create simple custom events for demonstrating expected shaking and warning time at any location in the reporting region.

Milestone 1.3.4: Develop and improve logging and monitoring tools

Items completed

- (CIT) Plog is being used throughout FinDer and eqInfo2GM codes. Log messages showing data statistics for FinDer and FFD2 have been added to aid connection problem troubleshooting.
- (UCB) Epic was modified to use the standard PLog API for all log messages.

Milestone 1.3.5: Unit and integration test design and implementation

Items completed

- (CIT) Updates have been made to the unit test framework to allow for more flexibility when testing with data files. Modifications are being made for unit testing of source code used for configuration file handling.
- (CIT) Unit test coverage for ffd2 and FinDer (in code review) has reached, or exceeded, the 40% target.
- (CIT) Unit test coverage for eqInfo2GM has reached, or exceeded, the 40% target.
- (CIT) Unit test coverage for station notification library has reached, or exceeded, the 40% target.
- (UCB) All recommended changes resulting from the implementation of unit tests were made to the Epic code.
- (UW) Unit test coverage report and test output automatically generated for the master branch
- (UW) Implemented additional unit tests for dmlib, SA/DM, Epic.

Milestone 1.3.6: Continue to implement code standards: format, cppcheck

Items completed

- (UCB, CIT, UW) This is ongoing work within SMWG

Milestone 1.3.7: Technical writing: code documentation (wiki and doxygen)

Items completed

- (UCB) Several documents were written that describe the Postgres database that supports the DM Review Tool. This database contains information from the EPIC, SA, DM, and ActiveMQ log files and is available to all users that have access to the EEW development machines.
- (CIT) Design documents: For all major projects, design documents were created in the central repository to document requirements, specifications, progress, decision points and testing. These are: station notification library, ground motion association (CDM), FinDer magnitude evolution, FinDer fault-specific and multi-templates, eqInfo2GM look-up tables.
- (UCB, CIT, UW) Doxygen: in-code documentation has been maintained or increased, including for all new code developments.
- (UCB, CIT, UW) Wiki: all new code developments submitted for testing have been documented on the wiki, including configuration changes, and new flow charts of code logic have been created.

Goal 1.4: System administration, operation and maintenance of the IT infrastructure

Milestone 1.4.1: Support USGS in 24/7 operations

- (UCB, CIT, UW) Responded to server and network equipment alerts 24/7.
- (UCB, CIT, UW) Continued to support USGS: participating in all elements of dataflow from the network to ShakeAlert, IT Network architecture, and system operations and integration.
- (UCB, CIT, UW) Monitored and maintained environmental systems in support of EEW servers. This included computer rooms with proper air conditioning and electrical supply. Maintained and operated ancillary equipment like UPS and generators to support the computer rooms.
- (CIT) Maintained NAS device for storing logs and computer backups for EEW servers, including production, int/dev, and test servers.
- (UCB) Created a secondary data center in McCone Hall to support alternative ShakeAlert systems and seismic data acquisition in the event that the primary data center in Warren Hall is taken offline for maintenance or is otherwise incapacitated.
- (UW) Maintained duplicate server facilities in separate buildings connected by dedicated fiber link. Redundant bonded network connections to the public network on primary site. Moved public-facing alert servers to University-operated central facility that is better equipped to handle security and network traffic surges expected in a large event.

Milestone 1.4.2: ShakeAlert system support and maintenance

Items completed and ongoing – System security:

- (UCB, CIT, UW) Supported monitoring and upgrades of systems including assistance during deployment of new integration and test servers

- (UCB, CIT, UW) Managed host-based firewalls for ShakeAlert systems, allowing access to ShakeAlert collaborator IP networks and TCP/UDP ports as requested by the ShakeAlert DevOps team and ShakeAlert collaborators at other centers.
- (UCB) Maintained a list of public SSH fingerprints for ShakeAlert systems on the ShakeAlert wiki page to give ShakeAlert operators and developers an alternative channel to verify the identity of new ShakeAlert systems.
- (UCB, CIT, UW) Participated in the ShakeAlert IT security working group to produce recommendations for the Regional Network Managers regarding security best practices for seismic networks.
- (CIT) Used a centralized syslog server to collect systems logs from all servers. With the help of Caltech IMSS security monitor all the server system logs for malware and other signs of suspicious activity.
- (UW) Maintain SELinux security enforcing infrastructure on UW-based servers.

Items completed and ongoing – Code/build deployment:
- (UCB, CIT) Maintained development and build systems to create and install new EEW source code.
- (UCB) Helped test installing ShakeAlert software dependencies.
- (CIT) Maintained the source code repository for EEW software.
- (UW, UCB) maintained local RHEL system patch repository point-in-time snapshots so that all systems are updated to a tested and consistent state.

Items completed and ongoing – Maintain and improve system management tools:
- (UCB, CIT) Maintained the Puppet configuration management server for ShakeAlert development and integration systems.
- Planned and coordinated the effort to upgrade Puppet software from its end-of-life version to a fully supported version on all ShakeAlert systems being managed by Puppet.
- Determined and implemented changes to the Puppet manifests necessary for upgrading from the end-of-life version of the Puppet software to a fully supported version.
- Renewed the Puppet certificate authority and public key infrastructure securing communications with ShakeAlert systems in the development and integration environments.
- Maintained virtualized ShakeAlert systems to test the deployment of new Puppet configurations.

Items completed and ongoing – Support EEW developers and development:
- Maintained and monitored a development system to create new ShakeAlert source code.
- Added accounts for new contract developers on ShakeAlert development and build systems, and made sure they had access to ShakeAlert systems through bastion hosts.
- Maintained an SSH bastion host to allow ShakeAlert developers and operators to access ShakeAlert development systems from collaborator IP networks.
- Helped set up contract developers with earthworm message rings and ActiveMQ accounts.

Items completed and ongoing – Expand operational support documentation and procedures:
- Outlined and documented the process for configuring a postfix mail transfer agent with DomainKeys Identified Mail for Nagios monitoring systems.
- Documented the process for adding a new ShakeAlert host to the network, with guidance for DNS entries and the necessary access through TCP/UDP ports.

Items completed and ongoing – Developing monitoring methods:
- (UCB) Outlined and documented the process for configuring Nagios monitoring servers to use Verizon's Enterprise Messaging Gateway to send SMS alerts to on-call duty operators.

- (CIT) Monitored and maintained NAGIOS to alert for server and networking issues.
- (CIT) Used SeisNetWatch(SNW), NAGIOS, cacti, AirVantage Management System (AVMS) and other scripts to monitor the continuous data streams.
- (CIT) Responded to request by EEW group and replaced server used for ci-dev1 with system that has faster CPU, more memory and more hard disk space.
- (CIT) Maintained a centralized EEW ActiveMQ broker (scsnbroker1) for forwarding eew-notify re-center messages sent to production and development systems. Updated the scsnbroker1 server with additional security and encryption for messages to use SSL certificates.

Milestone 1.4.3: ShakeAlert data feed support

Items completed

- (UCB, CIT, UW) Integrated new seismic stations into continuous data stream. Input metadata and other information related to new stations so they could be used by EEW system.
- (UCB, CIT, UW) Coordinated and supported new station acceptance tests for approving sites for EEW.
- (UCB, CIT, UW) Maintained and monitored networking and systems to ensure delivery of continuous seismic data streams to all EEW servers.
- (UCB, CIT, UW) Monitored and stored data latency parameters per stations for identifying historically latent stations or patterns in station latency.
- (UCB) Implemented archival of real-time geodetic data streams at UCB/NCEDC for the BK, CI, NC, PB and PW networks covering ~1083 west coast real-time GNSS stations. For each data “solution” 8 channels are archived, including latency (L1Z) channel. The data are archived in miniSEED format with blocksize of 512 bytes.
- (UCB) Maintained the networking support required for multicasting the continuous seismic and GNSS data streams for providing real-time data to all ShakeAlert servers.
- (UCB) Coordinated and supported new station acceptance tests for approving sites for ShakeAlert.
- (CIT) Maintained separate multicast network for GPS/GNSS data to receive RabbitMQ messages and multicast for use by all EEW servers. Also provided support to developers of geodetic algorithm BEFORES (Milestone 1.2.5).
- (CIT) Installed four new data acquisition servers to replace aging systems. These new acquisition servers will support continuous real-time seismic feed from stations.
- (UO) UO is responsible for a growing number of direct station imports. As of June 2020, UO directly imports 25 stations. No AQMS instance is in place at UO (nor is it being planned), all data are routed to a secondary import at UW. As of June 2020, UO has hired a systems administrator (Mats White) to take the lead on all data operations. Over the next few months, he will lead the process of purchasing a new import server, installing in UO’s computing colocation facility, and develop UO-internal networking between a variety of on campus assets.
- (UW) Rapid increases in the number of stations deployed motivated the addition of two new data import servers and a staging server. Many radio and cell modem telemetry connections were upgraded and reconfigured to provide necessary increased bandwidth and decreased latency. Enhancing security along the entire data path is a constant effort motivated by the Increased sophistication of attackers and security requirements imposed by our remote network hosts.

Update from EEW Coordinators:

During the reporting period, the Regional Earthquake Early Warning Implementation Working Group, REEWIWG, or REI for short, has engaged in multiple projects and improvements. They continue to evaluate and modify the station acceptance procedure and expand the capabilities of the station acceptance tools. Igor Stubailo has upgraded the Phase II tool to an interactive GUI that returns latency and triggering results for both EPIC and Finder algorithms. We finalized the requirements documentation to develop a continuous monitoring tool for the stations in ShakeAlert, and approved the first Phase with the RSNMWG. Our draft dashboard that included triggering, latency and RMS values using the SQUAC platform was presented to the RSNMWG in July 2021. Our USGS REI members continue 24/7 EEW Duty Review to evaluate ShakeAlert Messages for M>=4.0 and distribute detailed information about the event including delivery times and mapped alert areas. The REI has also finalized a procedure for removing and adding stations to the Suspended (formerly called the black list) and Conditional (formerly called the grey list) channel lists. The existing Earthworm tool (latency-L1Z) has been modified by ISTI and the current latency code tool has been installed and now operates and archives L1Z at each hub. Once the newest version of the latency tool is documented in aGitHub repository, the REI group will distribute the updated tool to the RSNs for implementation. The REI group presented seismic station acceptance standards to the GNSS working group in advance of the incorporation of GNSS data into ShakeAlert. The GNSS Data working group will spearhead the effort to implement motoring standards for the GNSS data moving forward.

The REI group continues to evaluate each procedure and corresponding requirements documents in order to incorporate the knowledge and experiences from new events and modifications to algorithms. As a result of the Antelope Valley earthquake sequence, the REI group is working on implementing action items based upon the after-action report. One of the most important issues that impacted the earthquake locations was the lack of station coverage and station spacing in the epicentral area. The REI group implemented several changes to the station acceptance process to expedite the inclusion of new stations to ShakeAlert. There is a standing agenda item at every REI group meeting to bring up any potential issues related to the station acceptance process as well as a problem-station dashboard. These two changes have enabled tremendous progress to be made in making sure that stations from contributing partners are incorporated into ShakeAlert quickly. The REI group has also embarked on an effort to look at stations that contribute to ShakeAlert but are not included in the core 1675 number that is required in the ShakeAlert TIP. The REI group coined the core/non-core term to distinguish these stations and is examining the possibility that stations might be too close together within a TBD range. We continue to look at station spacing, paying particular attention to new non-core stations coming into ShakeAlert.

One new member was added to the REI this year, Mario Aranha from UCB. Mario was added at the request of the project scientist to have GNSS representation in the coordination efforts for ShakeAlert. Fabia Terra is currently serving as our leader and serves as a liaison with the RSMWG. The REI group is excited to continue to develop tools for ShakeAlert and improve communication for the project.

Goal 1.5: Expansion of user engagement; development of system-wide shared web portal

ShakeAlert became ‘open for business’ in 2018, which allowed pilot partners to commence limited public alerting in California, Oregon, and Washington. In October 2019, this coverage was expanded with the announcement of public alerting in California through the Wireless Emergency Alert system and apps such as the UCB MyShake app. And in 2021, Oregon and Washington rolled out ShakeAlert public alerting across both states.While public alerting across the West Coast is a big step toward full adoption of EEW in the US, we still have a long way to go in terms of user engagement and automated alert delivery.

Members Strauss (UCB), Walsh (UO), Vinci (CIT), Steele (UW), Lotto (PNSN), and newly hired Edgecomb (UCB) of the Technical User Working group (TUWG) worked to usher stakeholders into this new era public rollout.

Strauss, Walsh, Vinci, Lotto, Edgecomb and Steele worked collaboratively to share partner successes, share partner roadblocks, and to stream-line partner involvement in the system via membership on the State ShakeAlert Committees (i.e., WACCEO, ORCCEO, and CACCEO), JCCEO Working Groups (e.g., ERWG), and JCCEO Focus Groups (e.g., Nusura, ShakeAlert Messaging Toolkit). TUWG focused their work on partners in the following 5 high impact sectors: education, healthcare, emergency management, transportation, and utilities.

TUWG presented to prospective ShakeAlert technical partners at the:

- Water Systems Earthquake Resilience Symposium
- California Healthcare Conference
- Electrical Power Resilience Symposium
- SoCal Lifeline Symposium
- San Diego Homeland Security Conference
- San Diego Emergency Management Conference
- SoCal Education Workshop
- Earthquake Country Alliance Northern California
- Earthquake Country Alliance Southern California
- American Geophysical Union Fall Meeting
- October 2019 public rollout media event SF City Hall
- October 2019 ECA NorCal ShakeOut drill
- October 2019 Wix resiliency presentation
- 2021 Oregon Rollout Webinars - to Stakeholders and Public
- 2021 Washington Rollout Public Presentation
- FEMA Alert & Warning Technical Assistance Workshop
- League of Oregon Cities Symposium
- Oregon Rollout Webinars, for the public and stakeholders (x5)
- USGS ShakeAlert R&D Workshop

→ Due to Covid-19 restrictions, many in-person meetings and conferences were cancelled or significantly delayed in 2020. However, some transitioned to digital platforms during the reporting period.

TUWG continued to spear-head Quarterly Strategy Meetings between the USGS, the University PIs, and the TUWG to ensure mutual coordination between partner agencies. Four QSMs were held during the reporting period - October 2020, January 2021, April 2021, and July 2021.

System-wide shared web portal:
TUWG worked on the framework for a system-wide shared web portal. The team drafted requirements, auditioned several contact resource management software types, and sent a proposal to the USGS for our chosen suite: Atlassian. TUWG and USGS co-drafted the SOW for the Atlassian contractor, including functionality requirements and training. USGS adopted this software in December 2020. TUWG and USGS

co-drafted the SOW for the Atlassian contractor, including functionality requirements and training sessions; TUWG led the buildout of ShakeAlert instance and worked with the contractor one-on-one to ensure completion while staying within budget. TUWG

User engagement:
TUWG works to maintain relationships with partners and to encourage multi-state partnerships through development of technical education and training materials for end-users and promoting engagement with the ShakeAlert system and development of message delivery systems. TUWG successfully helped technical partners transition through the partner licensing overhaul during 2020.

Milestone 1.5.1: Integrate strategy for user engagement and licensing

- TUWG worked with de Groot (USGS) and Eng (USGS Technology Transfer Office) on the new Evaluation, Pilot, and License to Operate license types developed by the USGS.
- TUWG had the opportunity to ask questions and then developed three protocol documents based on the license framework. These protocols explained the full pathway that external partners would take to obtain credentials, submit their statements of work, and interface with the system and are fully integrated with the proposed contact management resource requirements and proposed workflow. These documents contributed to defining the new partner licenses of 2020.
- TUWG members developed partner checklists for onboarding users and developed guidelines for Pilot partners to follow the pathway to obtain access credentials, submit a statement of work and interface with the system. These documents contributed to defining the licensing pathway and the ShakeAlert Resource Management Platform.
- TUWG members developed technical project criteria for a partner to graduate from a Pilot to a Licensed Operator. These criteria contributed to defining performance standards for License to Operate conversion.
- TUWG engaged with prospective regional pilots and evaluators to encourage execution of the new license agreement, acquire information regarding the status of their projects, submit credential requests for new users and maintain user documents in compliance with licensing protocols. (See Goals 1.5.3 for a list of executed pilot agreements for this COOP period).
- Walsh (UO) led S.M.A.R.T. goal planning for TUWG, to define the groups priorities for the coming grant cycles. The goals focused on a targeted outreach strategy to new automated-action partners, improved partner communication, networking, and information sharing, creation of digital guides and tutorials to assist partner onboarding and project success.

Milestone 1.5.2: Develop ShakeAlert web portal - enhance system coordination

Two primary elements were proposed for this work plan: (1) Build a Resource Management Platform (RMP), and (2) Build a Developers Platform (DP) for external developers. The RMP was envisioned as a multi-module system that could coordinate and align activities and needs of existing working groups. The DP was envisioned to promote external development of novel, high-functionality, high-impact applications.

Resource Management Platform (RMP):

- TUWG developed a list of guidelines and requirements for the RMP.
- Requirements were constructed based on the newly provided license agreements, discussions with external partners, and Q&A sessions with de Groot and Eng and included: contact management, listserv generation and signup, end-user impact statement submission, vendor statement submission, guidance documents, end user status tracking, and up to date recommendations from working and focus groups.
- TUWG drafted a plan to use Atlassian software for the contact resource management and for project tracking management.
- Draft plan was presented to de Groot and is under review with the USGS.
- Strauss (UCB) created the survey instrument template and socialized it with the TUWG, who provided important edits and comments.
- TUWG and USGS co-drafted the SOW for an Atlassian contractor, including functionality requirements and training. The SOW includes a request for a Pilot to Licensed Operator conversion tracking tool, complete with checklists and deadlines.

Pilot Developers Platform (PDP):

- (CIT) Created example end-user java code for end-user GitLab portal. Examples for connections to alert servers, parsing XML health status and alert messages, use of ground motion contour and map components.
- TUWG manages the Developer Platform, now referred to as GitLab, as one of the TUWG SuperProjects, chaired by Strauss (UCB) and Lotto (PNSN).
- Strauss (UCB) drafted a guideline document that outlines goals for the PDP, ongoing responsibilities for the GitLab working group, as well as milestones, and timelines for implementation.
- TUWG completed the QuickStart guide (originally drafted by Biasi (USGS)). The QuickStart guide is an up-to-date connectivity guide which details system requirements, description of message types, and key considerations. Additionally, TUWG completed the Scenario Server Tutorial and Alert Updates Factsheet, and assisted USGS with a Cybersecurity FAQ.
- TUWG advocated for technical issue notification and follow up. In 2020, USGS released the USGS technical partner list-serve in coordination with TUWG.

Milestone 1.5.3: Expand user-engagement efforts; implement protocol for ease of entry

The new licensing structure delivered by the USGS provided the TUWG an opportunity to reassess onboarding protocols. The licenses are now provided directly on the website, which facilitates keeping up to date with new versions.

Fewer license applications were submitted over the entirety of 2020 due to the overhaul in licensing and partner requirements. Many Evaluators, Pilots, or Prospective Pilots status changed under the new licensing structure under the new licensing guidance. Some partners were reclassified as customers of an LtO, some Pilots reverted back to Evaluators, and some partners did not move forward with the program.

- TUWG Regional Coordinators turned their focus primarily towards submitting applications that enable high-impact, high-volume usership.
- Through 2020, TUWG encouraged execution of the new license agreements among its existing partners and kept these partners updated on any changes.
- Vinci (CIT) has been responsible for assisting ShakeAlertLA and QuakeAlertUSA with their app content, testing and conformance with USGS criteria and latency testing.
- Strauss (UCB, NorCal region) submitted 5 pilots which provide high-impact and high-volume usership: Beeper, Street Food Finder, Citizen, Argyle, and Clover. Beeper and Clover became pilots under the new licensing system in 2021.
- Vinci (CIT, SoCal region) submitted 11 new pilots for Newport Beach Fire, Singlewire, Port of LA, Good Seed, Metrolink, Biola University, Paramount Studio, Kinemetrics, Perspecta, Artisan Global and the City of Ontario. Two of these partners have completed their implementations. A second SoCal License to Operate was submitted to USGS and is waiting for approval. ShakeReady SanDiego/Peraton and Metrolink/RailPros became LtOs, Good Seed and Kinemetrics became pilots in 2021 under the new licensing system.
- Walsh (UO, Oregon region) submitted a pilot for Inflow Communications/Beaverton School District and extensively engaged the following companies one-on-one over the reporting period: Nike, Kaiser Permanente Regional, Salem-Keizer School District, PacifiCorp Power, Kinder Morgan, Chevron, Samaritan Pacific Community Hospital, E|C Electric, Farwest, KEZI Local News, and Bay Area Hospital. Inflow Communications became a Pilot Partner in 2021 under the new licensing system. Walsh developed and executed a strategic technical user education and communication plan with the League of Oregon Cities, an association that represents Oregon's 240 cities. The plan was adopted by the Special Districts Association of Oregon.
- Steele (UW, Washington Region) developed a media event for the 2019 ShakeOut with the Washington Geologic Survey and Office of Superintendent of Public Instruction. The event highlighted ShakeAlert's role in the State School Safety Program using a ShakeAlert triggered announcement to start the Drop, Cover and Hold On drill. Washington based LTO's have been very active. Varius Inc. installed systems with the City of Anacortes, North City Water, Silverdale Water, Northshore Utility District, Washington State EMD, Alderwood Water/Sewer, Lakewood Water, and the aforementioned Stanwood/Camano School District. RH2 has installed systems with Lake Whatcom Water and Sewer District, City of Stanwood, and the City of Lynnwood Public Works Dept. Fifteen other implementations are contracted for and underway in Washington State and the ShakeAlert in Schools committee has reformed to establish new k-16 pilots.
- TUWG generated guidelines and various resources which were presented as recommendations to be hosted in the web portal.
- In 2020 and 2021 TUWG developed and distributed a survey for ShakeAlert Pilot partners and Licensed Operators to gather updated information about their company, project status, roadblocks, issues, or new points of contact.
- TUWG organized and directed the first Technical Partner Forum, a sharing and discussion platform specifically for ShakeAlert Technical Partners. Four Technical Partner Forums were held - October 2020, January 2021, April 2021, and July 2021.

- Lotto (UW), Walsh (UO), and Vinci (CIT) worked closely with Nusura to develop a messaging toolkit targeted at Emergency Managers during Year 1 of Nusura's contract. TUWG assisted Nusura in Year 2 of their contract on developing sector-focused messaging toolkits for the Utility, Transportation, Healthcare, and Education sectors.

Creation of Super Projects:
The goal of the Technical User Education and Training SuperProject is to (1) provide guidelines to technical users that will assist them in developing their ShakeAlert education and training plan for employees and clients and (2) develop vetted "off the shelf" education and training resources for technical partners. The goal of the Technical User SuperProject is to develop resources that answer frequently asked technical questions and assist partners with their implementation.

- TUWG manages the Technical Education and Training SuperProject, co-chaired by Walsh (UO) and Vinci (CIT).
- Walsh (UO) and Vinci (CIT) drafted the guideline document that outlines the requirements for a technical partner's education and training plan and required ShakeAlert materials. The Education and Training Plan was presented to de Groot and approved in July 2021 and uploaded to shakealert.org.
- Walsh (UO) and Vinci (CIT) drafted training modules, a resource user guide, documents describing how to write an SOW, pathways required to become a technical partner, and other helpful organizational tools for technical partners.
- The Technical User GitLab SuperProject, which is chaired by Strauss (UCB) and Lotto (PNSN), was explained earlier under the Pilot Developer Platform milestone (Milestone 1.5.2).
- In collaboration with Nusura and other JCCEO Working Groups, TUWG developed Messaging Toolkits to be used for both SuperProjects including: trademark logos, graphics, talking points, FAQs, earthquake education, technical partner project demonstrations, ShakeAlert overview and messages, protective actions, expected warning times.

References

Graves, R.W., B. Aagaard, K.W. Hudnut (2011). The ShakeOut Earthquake Source and Ground Motion Simulations. *Earthquake Spectra,* **27(2)**, 273-291.

Wirth E.A., A.D. Frankel, N. Marafi, J. E. Vidale, W. J. Stephenson (2018). Broadband Synthetic Seismograms for Magnitude 9 Earthquakes on the Cascadia Megathrust Based on 3D Simulations and Stochastic Synthetics, Part 2: Rupture Parameters and Variability. *Bull. Seism. Soc. Am.,* **108(5A)**, 2370–2388.

TASK 2.1: IMPROVING ANSS AND GNSS NETWORKS TO SUPPORT SHAKEALERT IN THE NORTHERN CALIFORNIA SEISMIC SYSTEM (UCB)

In Northern California, the members of the Northern California Seismic System (NCSS) - the joint earthquake monitoring efforts of the USGS Earthquake Monitoring Program and UC Berkeley in Northern California - continue to coordinate network improvement activities between the two centers, as well as with other West Coast partners, as we move toward the full implementation of West Coast ShakeAlert.

For funding through this proposal, the BSL's Task 2 efforts in Northern California encompass the following activities, for which we provide updates.

- ### 2.1.1: Upgrade of GNSS sites operated by UCB:

  UCB continued upgrading its GNSS network. During the project interval, UCB replaced equipment at 31 GNSS sites. This includes the purchase and installation of Septentrio PolaRX5 receivers. UCB also upgraded the infrastructure at 5 sites (BRI2, HELP, PTRL, SOD2 and UCD1). The work included the replacement of bracing systems, receivers and antennas.

- ### 2.1.2: Telemetry Hub Sites:

  The role of the telemetry hub sites is to collect data from other nearby seismic and geodetic stations and forward those data to a microwave relay operated by the USGS or CalOES. This tasks initially included the construction of four telemetry hub sites. Two telemetry hub sites were constructed at MZTA NS0128 (Manzanita Mountain) and GHOP NS0033 (Grasshopper Peak). The work included the installation of the telemetry infrastructure as well as the construction of a larger concrete pad (compared to a standard seismic site) and of telemetry antenna mounting hardware, power infrastructure and supplies.

  During the project interval, the USGS EMP and UCB concluded that only two of the four planned hub sites would be mutually beneficial to the USGS EMP and UCB. A request to repurpose the funds allocated to the construction of these two additional hubs sites was submitted and approved. Instead, 7 seismic sites were constructed. The two telemetry hubs sites and seven seismic sites are listed in Table 2.1.2.1.

Site Name	Site Description	Latitude	Longitude
NC.MED	Lake Edison	37.35833	-118.99750
BK.AASB	Arroyo Seca	38.43022	-121.10954
BK.BLAS	Black Lasic, Six Rivers NF	40.322637	-123.532583
BK.SANG	Sanger Peak, Six Rivers NF	41.910428	-123.64936

BK.GHOP	Grasshopper Peak, Humboldt SP	40.306967	-123.977983
BK.MZTA	Manzanita Lookout, Modoc NF	41.277941	-120.801222
BK.MILL	Mill Creek, Mill Creek SP	41.705342	-124.04107
NC.LSB	Steamboat Mountain	41.69729	-122.47139
NC.GRO	Round Mountain	39.91691	-122.67120

- 2.1.3: Purchase of radio communication equipment:

UCB purchased 42 900 MHz ISM radio pairs to be used for transitioning data transmission from some stations onto the CalOES and USGS microwave system. This includes the purchase of:
· 20-Xetawave Xeta9 single radio units
· 10-Xetawave Xeta9x9 dual radio units
· 8-Cambium CnReach single radio units
· 4-Cambium CnReach dual radio units

Thus far six connections have been transitioned to CalOES PSC and USGS microwave towers (BK.JEPS, BK.RUSS, BK.BARR, BK.DCMP, BK.TWIT, BK.BJES).

- 2.1.4: Supporting the build-out of seismic and geodetic stations:

UCB continued to support the build-out of the ShakeAlert seismic network through (a) coordination of seismic and geodetic station locations, (b) permitting and environmental documentation (NEPA, CEQA), (c) evaluation, quality control and acceptance of new and existing seismic stations for use in ShakeAlert, (d) documentation of instrumentation and metadata, and (e) other activities related to data flow and collection.

At the present time, UCB has secured 47 permits for site construction, and 15 additional permits are being processed. Of the 47 permits, 21 are on USFS property and 1 is on NP property. Since August 15, 2019, UCB has also transitioned 52 seismic stations into the EEW production system. This includes 31 stations constructed and installed by UCB, and 21 stations delivered by the California Geological Survey. Metadata for all new stations installed and operated by UCB are entered into the Station Information System (SIS) operated by Caltech, and metadata are retrieved for use with ShakeAlert and with the AQMS system used for regular earthquake reporting. The data from the stations undergo the quality control process developed by the ShakeAlert coordinators before they flow into the ShakeAlert production system.

Task 2.2: Improving the SCSN to Support ShakeAlert with USGS Pasadena (CIT)

2.2.1: Seismic Stations

2.2.1.1: New EEW seismic stations

No new USGS-funded EEW seismic stations were proposed in this Task.

2.2.1.2: Refurbish existing seismic stations

The proposed refurbishment of 6 stations has been completed. These six stations had new or improved postholes constructed, and were instrumented with new Q8 dataloggers and Omnisensor seismic sensors. Solar power and electronics were also completely overhauled or replaced, and old infrastructure was removed/remediated if applicable:

No.	Code	Name	Latitude	Longitude	Nearest City
1	**CI.NEE**	Needles	34.7675	-114.6188	Needles
2	**CI.BOR**	Borrego	33.2682	-116.4171	Borrego Springs
3	**CI.JVA**	Johnson Valley	34.36622	-116.6126	Yucca Valley
4	**CI.DNR**	Dunn Ranch	33.56667	-116.63056	Anza
5	**CI.LDR**	Leduc Ranch	34.9906	-118.34156	Tehachapi
6	**CI.PTD**	Point Dume	34.00443	-118.80686	Malibu

2.2.1.3: GFE Equipment Request

We deployed all of the Government Furnished Equipment (GFE) that we received. They were used to replace the dataloggers and sensors to upgrade beyond-life equipment.

2.2.2: Radio Telemetry Upgrade Project

2.2.2.1:

- Significant progress has been made on the Desert Loop and we completed the project. Installed new 4.9Ghz radios on backbone links at the following sites: XSSW, XBOM, XCTC, XWP7, XPDT.   Those sites also have cellular modems in place as a backup providing additional switchover data links.

- Replaced many older radios with new Cambium N500 900MHz spread spectrum hardware. Where it was necessary, the cables and antennas we replaced as well.
- Mt Hollywood: The site has an existing concrete pad. The team has removed an existing cabinet, painted the pole, and redid the fence. We are waiting for an installation permit from the Department of Parks and Recreation.
- Analyzed telemetry connections for bandwidth and throughput capacity and assigned a letter grade to each link. Used latency to estimate the performance of telemetry links by stopping and restarting data during the Data Recovery Test, i.e., the time it takes for a datalogger to deliver all the missing data after a short predefined outage (15 min). Each link was assigned a grade based on the time duration it took to return to the pre-test latency values (Figure 2.2.2.1). The method was initially applied only to the Q330 dataloggers' telemetry.
- Updated most of the Rockhound digitizers (Basalts and Obsidians) to collect 100Hz and 200Hz data onboard. The 200Hz data would be retrieved after an event or when needed. The 100Hz is used for the archive completeness. Both types will be downloaded by the Gap Fetcher.
- New Earthworm Latency module: contracted ISTI to improve the current module. It will be included into the EW distribution and with new features like an ability to replay the event data with original latency with a purpose of training ShakeAlert algorithms. The module is being tested and evaluated and when done, wil be installed by all West Coast EEW centers.
- Analyzed latency for all stations with cell modems that were moved to Verizon Broadband Mobile Priority after several seismic events, we verified that there were no issues with a new plan.

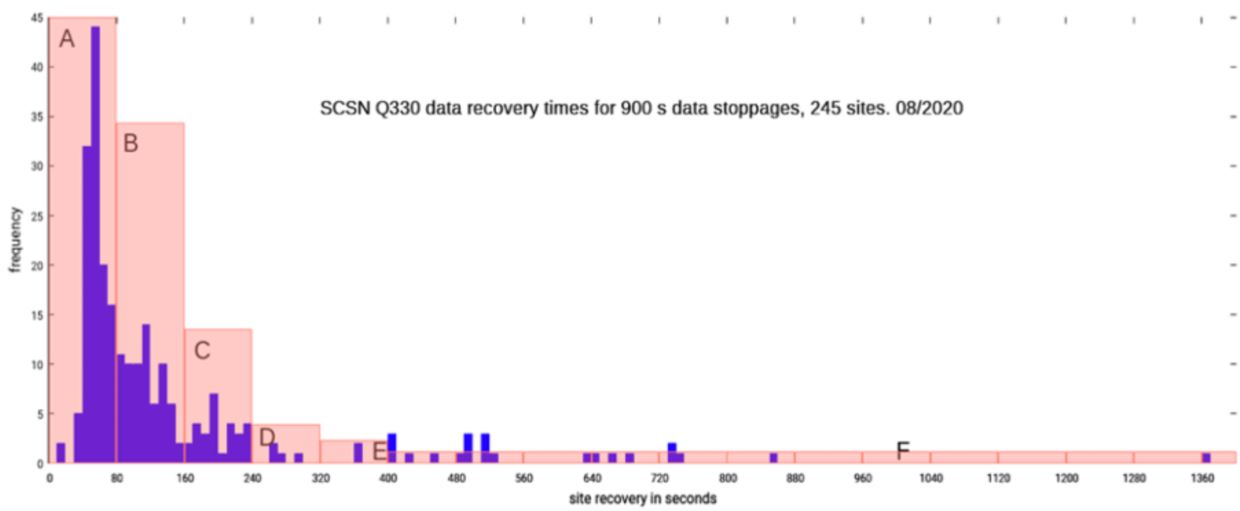

Figure 2.2.2.1. *Histogram of all sites used (Y axis) with recovery times (X axis) with grades assigned (A through F)*.

2.2.2.2: Radio telemetry Cal OES/PSC

- We worked with CalOES to select 100+ SCSN sites to connect to their microwave towers to diversify our telemetry and to improve the data latency and connection reliability.
- 50 radios, as well as antennas, cables, and VPN routers/firewalls have been purchased for this project and furnished to Cal OES.

- Installation of this equipment by Cal OES and Caltech/USGS staff began in 2020. As of September 2021, two tower sites have been brought into our network with dedicated MPLS connections provided by Cal OES's microwave network:
  - Government Peak: Supports about 16 seismic and GNSS stations in the Laurel Mountain/China Lake region.
  - Strawberry Peak: Supports about six seismic and GNSS stations with direct radio shots to Strawberry Peak, and also provides a valuable secondary access point into SCSN’s existing backbone microwave network.
- Preliminary work, including radio installation, has been completed by Cal OES in at least two additional tower locations (Cactus City and Pelato Mountain). Work at 10+ more tower locations is pending, and is mostly out of SCSN’s control (subject to Cal OES’s technician availability and partner agency requirements). SCSN is prepared to install the needed radios and routers at individual seismic stations as additional towers come online.
- CalOES configured and shipped 16 spread spectrum radios with tested antennas to Pasadena to be used at the planned microwave sites.

2.2.2.3: Radio telemetry relay hubs

- The site enclosure, power/solar equipment, and radio equipment for the Mount Hollywood site has been purchased and delivered. Ten XetaWave radios have been purchased for this project.
- Initial infrastructure, including a fence and an antenna mast, have been installed at Mount Hollywood. SCSN is waiting for additional approvals from the City of Los Angeles before work to install the enclosure, power system, and radio equipment can proceed.

2.2.3: Optimizing the SCSN for EEW

2.2.3.1: Individual Station Maintenance and Enhancements

Accomplishments as of August 2021:

- Added improvements to scsnbroker1 that include 1) security measures that only authorized clients using the appropriate ActiveMQ ports are allowed to send encrypted messages using SSL certificates to the scsnbroker. 2) Moved the scsnbroker1 server behind a perimeter firewall and configured server to use IP tables to restrict unauthorized access. 3) Virtualized the server running scsnbroker1 so we have more flexibility to deploy and manage the system.
- We are currently working on adding sanity checks to prevent a malformed message or a malicious party from disabling a large group of stations. Had discussions in the EEW production group and is currently working on a preliminary design to implement this check.
- As part of the continuous monitoring effort, we developed visual tools to track latency and packet size for data arriving from the dataloggers, all EPIC triggers with event contribution triggers by mining EPIC log files, and FinDer triggers by analyzing the FinDer logs. The results are also provided in a map view. The code runs automatically bi-weekly to produce plots for 15 RSN contributing networks on the West Coast.

2.2.3.2: Systems Level Network Engineering, Maintenance, and Enhancements

Ongoing security maintenance:

- Periodic network scans - working with the Caltech IMSS security team to frequently scan the SCSN network subnets to identify any open access points and vulnerabilities. Reports and recommendations are generated by Caltech IMSS and provided for us to act on.
- No new Q330 software updates have been released by the manufacturer in the past year. All Q330 series data loggers are still running the most recent software version.
- Q330s are scanned daily to ensure their login and authorization credentials are up to date.
- We continue to keep software and firmware up to date on dataloggers, in order to apply important security and bug fixes from manufacturers. We have automated monitoring and deployment tools that allow us to do this on a large scale. We run weekly checks of software versions on our Obsidians and Basalts and well as monitor the system state of health: security, verifying if user accounts are locked; flash drive space, percentage of storage left and used; memory available and used.
- Most routers, switches, cell modems, and radios in the field and on the Caltech campus are kept up to date with the latest manufacturer software and firmware. (Including MikroTik, Sierra Wireless, Ubiquiti, XetaWave, etc.).
- Some Cisco routers and switches on campus and at field hub sites are very old and software updates are no longer available; the security risk is still low because these are behind firewalls and/or used for completely private networks. These devices will be replaced and upgraded as funding becomes available.
- We have begun to deploy new Cisco Nexus switches in Pasadena, and have replaced several of our oldest routers with new models. We have also deployed three Palo Alto firewall appliances to protect our core network.

Telemetry enhancements:

- We have continued to replace old 3G cell modems with new 4G-capable modems. Four sites remain on 3G, but we anticipate they will be upgraded by the end of 2021.
- IPv6 implementation has been postponed indefinitely. Verizon is currently still able to offer us static IPv4 addresses for our cell modems, and even if this service ends, we no longer require static addresses for our field sites if we implement VPN routers.
- All Verzon cell accounts with SCSN are using Mobile Broadband Priority (MBP). Theoretically, this would allow ShakeAlert to transfer seismic data without interruptions during large events.
- We measured the bandwidth (link capacity) of all accessible telemetry connections to almost 300 sites by transferring a 4MB file from each site. We tested the measurements while the seismic data flow was stopped and not and found little benefits stopping the data so in the future the bandwidth measurements will be less disruptive to the real time data delivery.
- We monitor latency regularly on a weekly basis. The summary is tabulated for each SCSN site, plotted on a map, and summarized for the entire network in histograms.

Dynamic routing upgrades:

- We have continued to implement dynamic routing (using OSPF) on our field telemetry paths and on our private network in Pasadena. The majority of our private network and VPN sites are now dynamically routed. We have completely transitioned our legacy EIGRP networks to OSPF, for interoperability with non-Cisco networking equipment. Many servers in Pasadena still have static routes manually defined, but we are gradually phasing these out.

- We have installed new Juniper SRX380 routers to provide core routing on our private network in Pasadena. These have mostly replaced the functionality of our old general purpose routers (ahi and pike), though some network segments are still being transitioned.
- IKEv2 protocol – changes to the VPN to use the newer IKE protocol to avoid device conflicts raised within private cellular network. Since T-Mobile provides us with dynamic IP addresses, there is a possibility of private IP address conflict. After we observed multiple conflicts and issues with stable VPN connections, we decided to use the newer IKE protocol.

Data security and firmware upgrades:

- Continued adding additional VPN connections to 'campus stations'. These are stations that are connected directly to the Internet using partner agencies like universities', colleges' and museums' network connections.
- Continued using security measures identified earlier on any replacement or new data loggers installed in the field. Security measures include locking down user accounts, using non-standard port numbers, using encrypted protocols and connections.
- Caltech and USGS have replaced our core firewalls with new Palo Alto appliances and have added perimeter firewalls on network connections to partner agencies like DWP, Edison, LACO Fire, etc. The new firewalls are configured to perform Intrusion Detection System (IDS) and Intrusion Prevention System (IPS) to detect and prevent potential attacks. The firewalls are updated to the latest stable OS software and firmware versions. Two of the firewalls are setup with the same configurations and are capable of working as a redundant pair.

Virtualized SCSN terrestrial servers upgrades:

- Continued our progress to virtualize additional servers and improve our virtualization operation. Upgraded VMware vSphere virtualization software with ESXi, which is an enterprise-class hypervisor for deploying and serving virtual computers. Added more memory and hard drive space to improve performance. Currently we have the following functions virtualized: data export servers, development, playback and test servers, local webserver, gitlab and documentation repo, scsnbroker1 and jump hosts.
- VMware vSphere Essentials Plus – configuring the two new dedicated storage units to the vSphere cluster. They will reduce downtime and provide more drive storage for the virtual machines cluster. Upgraded to the latest VMware ESXi and vSphere Essentials Plus software license and version on cluster. Additional features include detailed monitoring, high availability, and replication across the two clusters.
- vSphere live migration – Using Vsphere to allow live migration of virtual machines. Moved additional servers to the virtualization cluster using VMWare software.
- Additionally, we have migrated the Scsnwiki, scsnphotos, NetBox (IP management system), Unimus (router configuration and backup), GitLab, SVN, Puppet (configuration management), RT (ticketing system) and some ShakeAlert developement server to the virtualized VMware cluster. All virtual systems updated to latest RHEL OS security patches.

Perform periodic reviews of performance and fix issues; ongoing activities:

- We measure and monitor data and packet rates from each datalogger in the field.

- We monitor radio connections to better understand how to configure them in a complex RF environment.
- We have explored other procedures to measure the link bandwidth, like the data flooding available on Q330 digitizers. It allows us measure how the actual seismic data is being delivered, via the same software tools and port numbers, with the same data fragmentation and compression involved.

Central site operations and upgrades:

- Jump hosts (also called bastion hosts) – added two new hardened hosts to manage external user access to network. Configured new users and network connections to use the jump hosts to access to the SCSN and ShakeAlert network. Configured users with limited access from the public net only to authorized systems.
- NetBox IP address management tool – installed software called NetBox to manage IP addresses for SCSN domain. SCSN has three separate physical networks: Private, Public and Wavenet. It has become increasingly complex to maintain a consistent IP address scheme and document it properly. The NetBox software is allowing us to better plan and design our network and to manage IP addresses for SCSN domain. NetBox will replace the older /etc/hosts and other IP address storage methods. Currently NetBox is being used to store all the private network IP addresses. Netbox also stores the location of all network devices and provides geolocation capabilities and rack diagrams to planning purposes.
- FreeIPA user management system - We are in the process of migrating our user accounts and passwords to use FreeIPA. FreeIPA is an opensource identity management system which administers usernames and passwords for Linux and network accounts.
- Unimus and The Dude - We use Unimus to back up the configuration from all our routers and switches in Pasadena and in the field. It also allows us with change management and configuration auditing. We also use the Dude program to mass manage configuration and update firmware on all the MikroTik devices deployed across our network.
- Purchased four acquisition servers to import seismic data from field data loggers. We have formalized the AQMS build and deployment procedures. We have version controlled the source code, have a well-defined software build process, we use specific SVN tag numbers and a dedicated build machine. We also use kickstart for initial deployment of servers and Puppet, which is an industry standard configuration management software, to deploy and keep track of the version of AQMS software installed on our development, test, staging and production real-time systems.
- Installed a dedicated network to transport continuous GNSS multicast data between the acquisition server and all the data subscribers.
- We have built code that detects new metadata from SIS and will automatically load into a staging area. The code then detects if there would be any changes to EEW metadata lists.
- We have merged 64-bit branch and any other active branches into one branch, linux-dev-branch. All production software deployment checks out of this branch to build the code. Builds of the code are done on a separate server, and deployed to staging and production servers by Puppet.

Supporting metadata standards with SIS:

- We have modified the extStationXML loader to accept closed epochs. This allows users to begin using SIS by only requiring the most recent epoch be entered and then being able to the older epochs later. We held two training sessions for users – one for UCB and NCSN in February 2020, and another for NSMP in Oct 2019.

Computer Servers Equipment Requests:

- After consultation with EEW developers came up with specification for eew-ci-dev1 server replacement to match EEW productions systems and plan for future growth. Purchased new Dell server as replacement for the existing eew-ci-dev1 system. The new server has better processing power (faster CPU with more cores) and has more memory to handle the new EEW algorithms including FinDer, PLUM and GNSS algorithms. The new server also has more disk storage to accommodate continuing and new development needs like storing large tankfiles for the ShakeAlert test suites and the result files. The new server has been performing well so far.

New ShakeAlert station acceptance:

- Developed a new station acceptance procedure for EEW. It involves seismic data and noise analysis, packet latency check, and EPIC and FinDer triggering performance check for 15 West Coast networks.
- The trigger values are mined daily and uploaded to a database. The results can be retrieved from a webpage and presented in a text and graphical form.

2.2.4: Prototyping the use of cloud computing (Amazon/AWS)

- eew-ci-dev system in cloud - Installed and configured an Amazon Web Services (AWS) Elastic Cloud Computing (ec2) instance as an EEW development server. Configured the server to receive redundant seismic waveforms for all SCSN stations from on-prem acquisition servers in Pasadena and from acquisition servers in AWS. We have been adding additional stations to the direct feed to Amazon AWS so if communications to Pasadena is not available, a second stream of data would still continue to flow to an acquisition server running in the AWS cloud.
- We are currently investigating the capabilities of the Sierra Wireless cellular modems to perform encrypted redundant VPN connections to both the acquisition servers, one terrestrial and another in the Amazon cloud.

TASK 2.3: IMPROVING ANSS NETWORKS TO SUPPORT SHAKEALERT IN THE PACIFIC NORTHWEST (UO, UW)

2.3.1 PNSN internal coordination

Coordination of PNSN operations at UO and UW is essential for cooperative operation of the network.

Management: UO, UW, and USGS all have representatives on the PNSN Leadership Group. This group convenes weekly to address PNSN strategies for management of personnel and resources, project prioritization, workflow troubleshooting, and other matters that affect the success of the network.

Equipment and Data Operations: PNSN team members belonging to Field and/or Data Operations participate in weekly meetings to consider systems administration, real-time data handling, equipment configuration, and data management. Data import operations are coordinated between USGS, UW, and UO staff, including management of import servers at UW and UO. PNSN has implemented a variety of internal tools aimed at efficient network monitoring and data collection. The IP address management (IPAM) software Netbox was deployed and adopted during the performance period, and its web application programming interface (API) has been used to integrate that information into the UW-hosted instance of Nagios for ongoing monitoring. Integration of these software packages has ensured consistency among UW, UO, and USGS staff in device nomenclature, polling of SOH variables, and consistent internal tracking of device addressing (internal and external IP, ports, and routing protocols). Expanded use of VPN tunneling has offered broader use of non-static addressing at host site locations, as well as better data security measures. New physical and virtual data import servers have been deployed to accommodate a growing number of stations and requisite imports to UW and UO-hosted earthworm instances. PNSN maintains redundant failover capacity to allow seamless OS and other upgrades without down time.

Field Operations: PNSN conducts field operations with a general split between Washington State and Oregon State station assignments. However, staff from both Universities and the USGS perform work in both states. Regular weekly meetings, shared data management, a shared ticketing system, and regular daily conversation ensure close coordination and assurance of design/deployment standardization. Standing meetings related to overall array buildout and permitting efforts allowed for coordination of Pacific Northwest buildout efforts. Specific to the working conditions forced by the emergent pandemic, PNSN staff organized a full month of topical information sessions on network operations. Within specific areas of expertise, staff generated tutorial and/or topic overview content presented via Zoom. This unique opportunity, in light of an extended period of travel freezes, allowed for a wide range of collaboration and sharing of experience across staff. Such collaboration offered training for new staff and tasked experienced staff to summarize practices and provide detail on operational workflows and logic.

External Relations: To ensure alignment of Pacific Northwest user engagement strategy, UO and UW staff meet weekly to discuss and plan strategy. Such efforts are then elevated to ShakeAlert-wide coordination under the purview of the TUWG and other JCCEO activities.

2.3.2 Network buildout and improvements

2.3.2.1 New construction and refurbished stations

Between August 15, 2019 and August 15, 2021, 55 new or refurbished seismic stations in Oregon and 115 new or refurbished seismic stations in Washington came on-line, for a total of 170 new or upgraded ShakeAlert-ready stations in the Pacific Northwest. The work of identifying sites and obtaining land-use and environmental NEPA-compliant permits for these sites was funded by this cooperative agreement, the supplemental funds to the previous cooperative agreement, and WA state's Emergency Management Department (WA EMD). Figure 2.3.2.1 shows the cumulative number of sites identified and land-use agreements signed ("Sited total"), number of environmental permits obtained ("NEPA total"), number of stations constructed ("Const/Install Total"), and number of new stations contributing data to ShakeAlert ("ShakeAlert Total"), as a function of time.

Of the 55 new stations in Oregon, 8 utilized capital equipment funds obtained through the State of Oregon Strong-Motion Instrumentation Program that is processed through the Oregon Department of Geology and Mineral Industries (DOGAMI), and 6 were partially funded by the State of Oregon ShakeAlert Bonding fund (OSB). 40 stations were fully funded by the USGS-ShakeAlert program (see Table 2.3.2.1). In Oregon, an additional 25 sites have been permitted and are ready for construction and installation (Table 2.3.2.2). In Washington, 31 of the 115 stations were largely funded by the state of Washington via a UW inter-agency agreement and contract with the WA Emergency Management Department (EMD), funded by a state budget appropriation. All the rest, 84 stations, were fully funded by this cooperative agreement (see Table 2.3.2.3). An additional 23 sites have been permitted and are ready for construction and installation (Table 2.3.2.4).

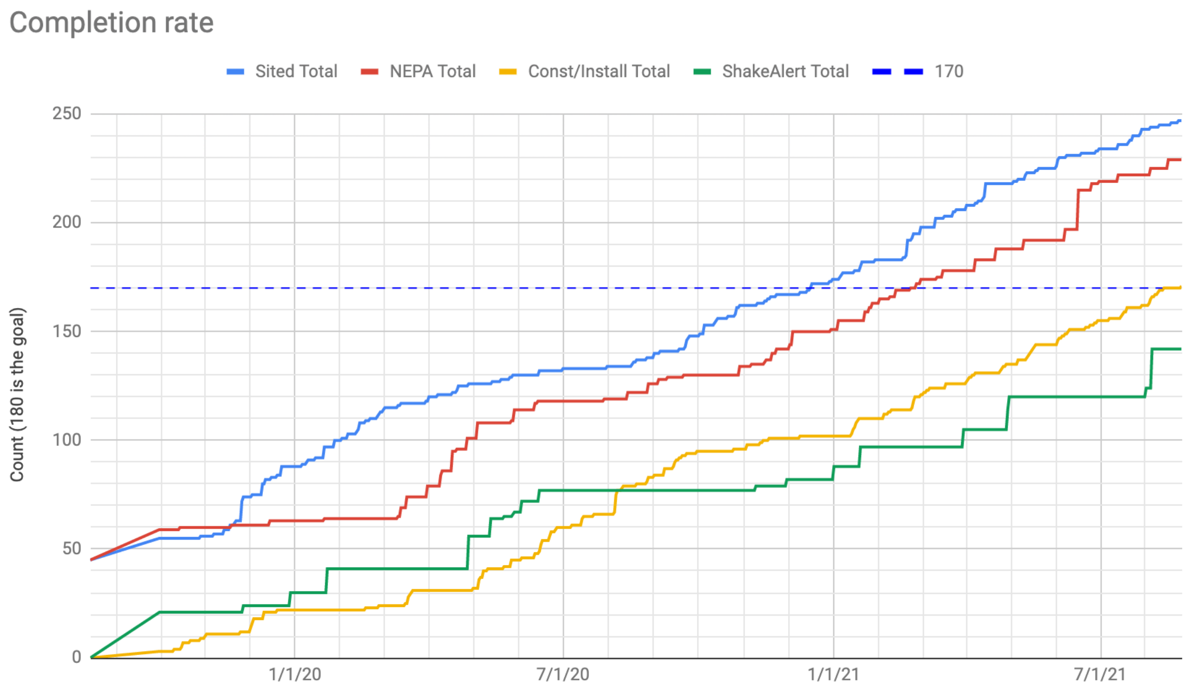

Figure 2.3.2.1. *The cumulative number of OR and WA sites identified and land-use agreements signed ("Sited total"), number of environmental permits obtained ("NEPA total"), number of stations constructed ("Const/Install Total"), and number of new stations contributing data to ShakeAlert ("ShakeAlert Total"), as a function of time.*

Construction and installation of the new sites was done by three groups, the UO field crew, the UW field crew, and a contractor's crew, Hastings Micro-Seismic Consulting (HMSC). In Oregon, the UO crew finished 23 sites, whereas HMSC (contracted by the UW) constructed and installed the other 32. In Washington, the UW crew finished 8 sites and the other 107 sites were constructed and installed by HMSC. For all sites, UW and UO personnel planned, designed, and established telemetry connections from the remote location to the datacenter at UW in Seattle. For a few dozen UO-network sites, the data are telemetered to UO first where they are forwarded to the UW.

Substantial effort was undertaken to establish coordinated installation activities with HMSC. An intermediate data import server was established, multiple layers of communication and document servers were deployed, and protocols for equipment preparation and exchange were established and revised as the project progressed. These resources proved essential for navigating UW Real Estate contracting processes, schedule refinement in light of an emergent and ongoing Pandemic, and careful handling of data importing and telemetry management. We anticipate that UO can leverage the same procedures and experience when they proceed with a contractor for construction and installation of many of the new OR bond-funded sites.

***Table 2.3.2.1**. Stations added in Oregon (55), in order of when they came on-line. Last column shows the date that the station started contributing to ShakeAlert. Key to column titles: Net code, FDSN network code; Sta code, SEED site lookup code; Counts?, 1=core station, 0=non-core station; Comment, new means new to ShakeAlert, refurbished/upgrade means that it contributed data before but has been significantly improved. SM, strong-motion sensor; BB, broadband sensor; SP, short-period sensor; Permits done, date last permit was signed (usually NEPA); Online, date when data started streaming to UW; Finding sources, primary funding source; Contributing, date when data started contributing to ShakeAlert.*

Net code	Sta code	Counts ?	Comment	SM	BB	SP	Permits done	Online	Funding sources	Contributing
UW	SSO2	1	new-PNSN build	X	X		6/4/2019	9/4/19	RFE-DOGAMI	12/29/2019
UW	BRAN	1	Refurbished	X	X		X	9/27/19		9/27/2019
UO	PF16	0	new-PNSN build	X			9/30/2019	10/16/19	RFE-DOGAMI	
UO	PF31	1	new-PNSN build	X			9/30/2019	10/17/19	RFE-DOGAMI	1/23/2020
UO	PF22	1	new-PNSN build	X			9/30/2019	10/17/19	RFE-DOGAMI	3/27/2020
UO	OTTR	1	new-PNSN build	X			6/17/2019	10/29/19	SA-GFE-OR	1/23/2020
UO	PF27	1	new-PNSN build	X	X		9/30/2019	11/1/19	SA-GFE-OR	6/29/2020
UO	PF25	1	new-PNSN build	X			9/30/2019	11/2/19	RFE-DOGAMI	1/23/2020
UO	RSBO	1	Upgrade	X	X		X	11/25/19	SA-GFE	6/29/2020
UO	DEPO	1	new-PNSN build	X			6/4/2019	12/2/19	SA-GFE-OR	1/23/2020
UO	LINC	1	new-PNSN build	X			7/23/2019	12/2/19	SA-GFE-OR	1/23/2020
UO	SLTZ	1	new-PNSN build	X			6/4/2019	12/3/19	SA-GFE-OR	1/23/2020
UO	WALD	1	new-PNSN build	X			6/17/2019	12/3/19	SA-GFE-OR	1/23/2020
UO	LAKE	1	new-PNSN build	X			6/4/2019	12/4/19	SA-GFE-OR	1/23/2020
UO	MPLT	1	new-PNSN build	X			6/17/2019	12/4/19	SA-UO-3	1/23/2020
UO	LOWP	1	new-PNSN build	X			12/15/2019	12/20/19	SA*	3/27/2020
UO	MONKS	1	new	X	X		6/17/2019	2/18/20	SA-WA-6	3/27/2020
UO	PRARI	1	new-PNSN build	X			3/17/20	2/27/20	SA*	7/30/2020
UO	IRYS	1	new-PNSN build	X	X		7/24/2019	3/16/20	SA-GFE-OR	5/13/2020
UO	CCSO	1	new	X			9/6/2019	3/18/20	SA-WA-3	5/13/2020
UO	ELSIE	1	new	X			9/6/2019	3/18/20	SA-WA-3	5/13/2020
UO	KNAP	1	new	X			6/4/2019	3/18/20	SA-WA-3	5/13/2020
UO	NBFR	1	new	X	X		7/23/2019	3/19/20	SA-WA-6	5/13/2020
UO	VITI	1	new-PNSN build	X	X		8/7/2019	3/20/20	SA-GFE-OR	5/13/2020
UO	LOKI	1	new	X	X		6/4/2019	3/21/20	SA-WA-6	5/13/2020
UO	PF10	1	new	X			9/30/2019	5/1/20	RFE-DOGAMI	8/28/2020
UO	MAPT	1	new	X			8/7/19	5/5/20	SA-WA-3	6/29/2020
UW	FISH2	1	new	X	X		3/31/2020	5/27/20	SA-WA-6	7/30/2020
UW	SEAS2	1	new	X	X		3/11/2020	5/27/20	SA-WA-6	7/30/2020
UO	BCAT	1	new	X			5/1/2019	6/3/20	SA-WA-3	7/30/2020
UO	RAID	1	new	X			5/1/19	6/23/20	SA-WA-3	9/25/2020
UO	KBO	1	contributing	X	X		X	6/26/20	SA-GFE-OR	8/28/2020
UO	KEB	1	contributing	X	X		X	6/27/20	SA-GFE-OR	7/30/2020

UO	MERL	1	new	X			6/5/19	7/7/20	SA-WA-3	8/28/2020
UO	DAYS	1	new	X			12/15/2019	7/14/20	SA-WA-3	8/28/2020
UO	HBUG	1	new	X	X		4/27/2020	7/14/20	SA-WA-6	8/28/2020
UO	CARP	1	new	X			6/12/2020	7/14/20	SA-WA-3	9/25/2020
UO	VINO	1	new	X	X		3/31/2020	7/15/20	SA-WA-6	9/25/2020
UO	SALT	1	new	X	X		5/29/2020	7/22/20	SA-WA-6	8/28/2020
UO	JAZZ	1	new-PNSN build	X	X		5/27/2020	8/20/20	DOGAMI	9/25/2020
UO	GROV	1	new	X	X		6/4/2019	9/8/20	SA-WA-6	10/30/2020
UO	LEWL	1	new	X			5/1/2019	9/8/20	SA-WA-3	10/30/2020
UO	RDEO	1	new	X			6/17/19	9/8/20	SA-WA-3	10/30/2020
UO	PERY	1	new	X	X		6/4/2019	9/23/20	SA-WA-6	3/5/2021
UO	WIKI	1	new	X	X		3/13/2020	11/12/20	SA	1/19/2021
UO	KUHN	1	new	X	X		6/12/2020	11/14/20	SA	1/19/2021
UW	RNO2	1	new-PNSN build	X			11/16/2020	12/09/20	SA	1/19/2021
UO	BENT	1	new-PNSN build	X			11/6/2020	2/24/21	SA	3/30/2021
UO	PF29	1	new-PNSN build	X			9/30/2019	3/18/21	SA-OR/OR State	4/29/2021
UO	PF09	0	new-PNSN build	X			9/30/2019	3/18/21	SA-OR/OR State	4/29/2021
UO	UCHR	1	new-PNSN build	X	X		3/13/2020	4/2/21	RFE-DOGAMI	4/29/2021
UO	TRIPT	1	new-PNSN build	X	X		8/21/2019	5/6/21	OR State 2021	7/16/2021
UO	SAUVY	1	new-PNSN build	X			5/29/2020	5/6/2021	OR State 2021	8/25/2021
UO	COBRA	1	new-PNSN build	X			7/24/2019	5/14/21	OR State 2021	7/16/2021
UO	LADD	1	new-PNSN build	X			10/29/2020	8/13/21	OR State 2021	TBD

Table 2.3.2.2. *Stations in Oregon (25) for which siting and permitting was completed, but construction and installation not yet done. An additional 9 have been sited but have not been permitted yet.*

Net code	Sta code	Comment	SM	BB	SP	Permit date	Funding source
UO	BASIN	new	X			6/16/2021	OR State 2021
UO	CHUCK	new	X	X		8/27/2021	OR State 2021
UO	COVE	new	X	X		3/31/2020	
UO	DEAN	new	X	X		2/1/2021	OR State 2021
UO	DUTCH	new	X	X		6/16/2021	OR State 2021
UO	EOU	new	X			10/15/19	OR State 2021
UO	FIDL	new	X	X		6/16/2021	OR State 2021
UO	GRSDL	new	X	X		8/27/2021	OR State 2021
UO	KALM	new	X	X		6/16/2021	OR State 2021
UO	KING	new	X	X		9/21/2020	OR State 2021
UO	LONE	new	X	X		6/4/2019	OR State 2021
UO	ONION	new	X	X		6/16/2021	OR State 2021
UO	PELI	new	X			6/16/2021	OR State 2021
UO	SKAN	new	X	X		6/14/2020	OR State 2021

UO	SLPT	new	X	X		6/16/2021	
UO	SNAKE	new	X			6/16/2021	OR State 2021
UO	TBLE	new	X	X		1/4/2021	OR State 2021
UO	VAUN	new	X	X		7/23/2019	RFE-DOGAMI
UW	MOON	new	X	X		6/16/2021	OR State 2021
UW	NCO	new	X	X		6/16/2021	OR State 2021
UW	TDH	new	X		X	6/16/2021	
UW	VFP	new	X		X	6/16/2021	
UW	VIP	new	X	X		6/16/2021	OR State 2021
UW	VLL	new	X		X	6/16/2021	
UW	VLM	new	X		X	6/16/2021	

Table 2.3.2.3. *Stations added in Washington (115), in order of when they came on-line. Last column shows the date that the station started contributing to ShakeAlert. Column titles have the same meaning as in Table 1.*

Net code	Sta code	Counts?	Comment	SM	BB	SP	Permit date	On-line	Funding sources	Contributing
UW	SEA	1	upgrade	X			N	8/15/19	SA	8/29/2019
UW	DONK	1	new-PNSN build	X	X		8/21/2019	8/29/19	SA	12/29/2019
UW	RPW2	1	new-PNSN build	X	X		8/21/2019	10/11/19	SA	12/29/2019
UW	PUPY	1	new-PNSN build	X		X	4/19/2018	10/22/19	SA	12/29/2019
UW	NAHC	1	new-PNSN build	X			3/13/2020	12/11/19	SA	1/23/2020
UW	TIOG	1	new-PNSN build	X			3/13/2020	12/11/19	SA	1/23/2020
UW	SDRO	1	new-PNSN build	X			11/19/2019	12/11/19	SA	3/27/2020
UW	MCLN	1	new	X			3/17/20	5/5/20	SA	6/29/2020
UW	PELL	1	new	X			4/9/2020	5/5/20	SA	6/29/2020
UW	TOKE	1	new	X			3/17/2020	5/5/20	SA	6/29/2020
UW	NINO	1	new	X			3/17/20	5/6/20	SA	6/29/2020
UW	BRPT	1	new	X			4/9/2020	5/8/20	SA	6/29/2020
UW	TUMW	1	new	X			4/10/2020	5/8/20	SA	6/29/2020
UW	TRFA	1	new	X			3/17/20	5/8/20	SA	7/30/2020
UW	ALLI	1	new	X			3/31/2020	5/11/20	SA	6/29/2020

UW	PASS	1	new	X	X			5/22/20	SA	5/22/2020
UW	BAYC	1	new	X			4/17/2020	5/27/20	SA	7/30/2020
UW	LAYC	1	new	X			4/10/2020	6/12/20	SA	7/30/2020
UW	TORK	1	new	X			3/31/2020	6/12/20	SA	7/30/2020
UW	NMDY	1	new	X			4/9/2020	6/15/20	SA	8/28/2020
UW	BLDG	1	new	X			4/9/2020	6/16/20	SA	7/30/2020
UW	HOMA	1	new	X			4/17/2020	6/16/20	SA	7/30/2020
UW	SPFR	1	new	X			4/20/2020	6/16/20	SA	7/30/2020
UW	BELF	1	new	X			4/27/2020	6/17/20	SA	8/28/2020
UW	GRIF	1	new	X			4/27/2020	6/17/20	SA	8/28/2020
UW	BRGL	1	new	X			4/27/2020	6/22/20	SA	8/28/2020
UW	SKIT	1	new	X			4/9/2020	6/22/20	SA	8/28/2020
UW	KELS	1	new	X			9/13/2019	6/23/20	SA	10/30/2020
UW	OAKH	1	new	X			5/29/2020	8/5/20	SA	1/19/2021
UW	BRAV	1	new	X			4/17/2020	8/6/20	SA	9/25/2020
UW	BTHL	1	new	X			4/17/2020	8/6/20	SA	9/25/2020
UW	EDSN	1	new	X			5/29/2020	8/6/20	SA	9/25/2020
UW	RVRV	1	new	X			5/4/2020	8/6/20	SA	9/25/2020
UW	STNW	1	new	X			5/4/2020	8/6/20	SA	9/25/2020
UW	WRMB	1	new	X			5/4/2020	8/6/20	SA	9/25/2020
UW	CUGR	1	new	X			5/4/2020	8/6/20	SA	10/30/2020
UW	SKGF	1	new	X			4/17/2020	8/6/20	SA	TBD
UW	BECK	1	new	X			5/4/2020	8/7/20	SA	9/25/2020
UW	KEYS	1	new	X			4/27/2020	8/7/20	SA	10/30/2020
UW	ERIE	1	new	X			5/29/2020	8/10/20	SA	10/30/2020
UW	CWFG	1	new	X			6/12/2020	8/11/20	SA	9/25/2020
UW	WYNO	1	new	X	X		9/13/2019	8/27/20	SA	10/30/2020
UW	WFHS	1	new	X			4/17/2020	8/28/20	SA	10/30/2020
UW	HILL	1	new	X	X		4/17/2020	8/28/20	SA	1/1/2021
UW	SALO	1	new	X	X		4/17/2020	9/1/20	SA	10/30/2020
UW	PURDY	1	new	X			8/14/2020	9/14/20	SA	10/30/2020
UW	SILV	1	new	X			5/4/2020	9/15/20	WA-2021	10/30/2020
UW	MACH	1	new	X			8/28/2020	9/15/20	WA-2021	11/30/2020
UW	TULA	1	new	X			8/28/2020	9/16/20	WA-2021	1/19/2021
UW	PRIN	1	new	X	X		4/17/2020	9/18/20	SA	11/30/2020
UW	HOHM	1	new	X			2/8/2019	9/20/20	WA-2021	11/30/2020

UW	SHUK	1	upgrade	X	X		6/16/2021	9/30/20	SA	10/30/2020
UW	OTR	1	new	X	X		7/29/2020	10/25/20	SA	1/19/2021
UW	BOGA	1	new	X			8/28/2020	11/3/20	WA-2021	1/19/2021
UW	BRUIN	1	new	X			8/14/2020	11/3/20	WA-2021	1/19/2021
UW	ORCA	1	new	X			2/12/2019	11/18/20	WA-2021	1/19/2021
UW	COOM	1	new	X			9/10/2020	1/13/21	WA-2021	3/5/2021
UW	BOOK	1	new	X			9/4/2020	1/14/21	WA-2021	3/5/2021
UW	ELGR	1	new	X			8/28/2020	1/14/21	WA-2021	3/5/2021
UW	LARL	1	new	X			12/4/2020	1/15/21	WA-2021	3/5/2021
UW	DLTA	1	new	X			12/4/2020	1/16/21	WA-2021	3/5/2021
UW	SMOO	1	new	X			12/4/2020	1/16/21	WA-2021	3/5/2021
UW	HFMN	1	new	X			11/20/2020	1/17/21	WA-2021	3/5/2021
UW	NBND	1	new	X			8/14/2020	1/18/21	WA-2021	3/5/2021
UW	CVSD	1	new	X			10/29/2020	2/4/21	WA-2021	3/30/2021
UW	SPOW	1	new	X			10/29/2020	2/4/21	WA-2021	4/29/2021
UW	LBRT	1	new	X	X		1/4/2021	2/7/21	WA-2021	3/30/2021
UW	RVSD	1	new	X	X		12/30/2020	2/9/21	WA-2021	3/30/2021
UW	SKYK	1	new	X			11/23/2020	2/23/21	WA-2021	3/30/2021
UW	WENA	1	new	X			9/4/2020	2/24/21	WA-2021	3/30/2021
UW	WTRV	1	new	X			1/25/2021	2/24/21	WA-2021	3/30/2021
UW	NTAT	1	new	X			11/20/2020	2/25/21	WA-2021	4/29/21
UW	MNSN	1	new	X			10/29/2020	2/25/21	SA	TBD
UW	TWISP	1	new	X	X		2/12/2021	3/1/21	WA-2021	3/30/2021
UW	SAW	1	new	X	X		1/4/2021	3/3/21	SA	4/29/2021
UW	OSQM	1	new	X	X		1/21/2020	3/5/21	SA	4/29/2021
UW	NATEM	1	new	X	X		2/12/2021	3/7/21	SA	4/29/2021
UW	ARTIC	1	new	X	X		12/4/2020	4/1/21	WA-2021	TBD
UW	LEID	1	new	X	X		12/2/2020	4/3/21	SA	6/10/2021
UW	DEAL	1	new	X	X		12/4/2020	4/5/21	SA	4/29/2021
UW	NEMA	1	new	X	X		1/27/2021	4/7/21	SA	6/10/2021
UW	GUEM	1	new	X	X		1/4/2021	4/24/21	SA	6/11/2021
UW	RNWY	1	new	X	X		4/7/2021	4/25/21	SA	6/10/2021
UW	SJIF	1	new	X			4/7/2021	4/26/21	SA	6/10/2021
UW	BOIS	1	new	X	X		4/7/2021	4/28/21	SA	6/10/2021
UW	CHIMA	1	new	X	X		1/22/2021	5/12/21	SA	8/25/2021
UW	HANS	1	new	X	X		3/12/2021	5/13/21	SA	7/16/2021

UW	PAN4H	1	new	X	X		4/7/2021	5/15/21	SA	7/16/2021
UW	DAYT	1	new	X			11/23/2020	5/16/21	SA	7/16/2021
UW	NEERS	1	new	X			3/16/2021	5/17/21	SA	7/16/2021
UW	DOTY	1	new	X	X		12/2/2020	5/18/21	SA	7/16/2021
UW	SCC2	1	upgrade	X			N	6/2/21	SA	TBD
UW	LCV	1	new	X	X		3/1/2021	6/3/21	WA-2021	8/25/2021
UW	TOUCH	1	new	X	X		4/21/2021	6/5/21	WA-2021	8/25/2021
UW	BICK	1	new	X	X		2/26/2021	6/7/21	WA-2021	8/25/2021
UW	WAHL	1	new	X			3/16/2021	6/9/21	WA-2021	8/25/2021
UW	UGSD	1	new	X			12/4/2020	6/10/21	WA-2021	8/25/2021
UW	ANGUS	1	new	X	X		4/21/2021	6/21/21	SA	TBD
UW	TBLMT	1	new	X	X		2/8/2021	6/24/21	WA-2021	8/25/2021
UW	LOKMT	1	new	X	X		4/21/2021	6/27/21	SA	8/25/2021
UW	BDGR	1	new	X	X		6/25/2021	6/29/21	SA	8/25/2021
UW	DY2	1	new-PNSN build	X	X		1/22/2021	7/7/2021	SA	8/25/2021
UW	HOQUI	1	new	X	X		6/7/2021	7/15/21	SA	TBD
UW	CPARK	1	new	X			4/7/2021	7/16/21	SA	TBD
UW	PALIS	1	new	X			11/20/2020	7/17/21	SA	TBD
UW	GRIZZ	1	new	X			3/16/2021	7/19/21	SA	8/25/2021
UW	MONTE	1	new	X	X		6/7/2021	7/19/21	SA	8/25/2021
UW	WPEQ	1	new-PNSN build	X	X		2/22/2021	7/29/21	SA	TBD
UW	ETW	1	new-PNSN build	X	X		5/10/2021	8/3/21	SA	TBD
UW	LYND	1	new	X			2/12/2021	8/4/21	SA	TBD
UW	SUMAS	1	new	X			8/4/2021	8/4/21	SA	TBD
UW	DMNG	1	new	X			8/16/2021	8/5/21	SA	TBD
UW	BHAM	1	new	X	X		6/25/2021	8/7/21	SA	TBD
UW	MULN	1	new	X	X		1/22/2021	8/9/21	SA	TBD
UW	SMSH	1	new	X			5/4/2020	8/10/21	SA	TBD

Table 2.3.2.4. Stations in Washington (23) for which siting and permitting was completed, but construction and installation occurred after 8/15/2021 or is not yet done. At the time of this writing, an additional 5 sites have been identified but have not been permitted yet.

Net	Sta code	Comment	SM	BB	SP	Permit date	On-line	Funding source

code								
UW	CONW	new	X			8/4/2021	8/25/21	SA
UW	GRNT	new	X			6/7/2021	8/26/21	SA
UW	COWS	new	X	X		1/22/2021	8/31/21	SA
UW	NEL	new-PNSN build	X	X		5/10/2021	9/1/21	SA
UW	SLF	new-PNSN build	X	X		5/10/2021	9/2/21	SA
UW	BHW	new	X	X		4/21/2021	9/07/2021	SA
UW	DOORS	new	X	X		7/13/2021	9/23/2021	SA
UW	MOODY	new	X	X		6/7/2021	9/23/2021	SA
UW	OWLS	new	X			1/27/2021	9/23/2021	SA
UW	WRW	new-PNSN build	X	X		5/10/2021	9/28/2021	SA
UW	HORSE	new	X	X		2/1/2021	TBD	SA
UW	SACA	new	X			2/26/2021	TBD	SA
UW	SAXON	new	X	X		3/1/2021	TBD	SA
UW	WATCH	new-PNSN build	X	X		11/15/2020	TBD	SA
UW	SKAMO	new	X	X		4/21/2021	TBD	SA
UW	LOPEZ	new	X	X		1/25/2021	TBD	SA
UW	EAGLE	new	X	X		6/7/2021	TBD	SA
UW	SKOKO	new-PNSN build	X	X		6/16/2021	TBD	SA
UW	HDW	new-PNSN build	X	X		6/16/2021	TBD	SA
UW	OSR	new	X	X		6/30/2021	TBD	SA
UW	OLGA	new	X	X		7/13/2021	TBD	SA
UW	MORSE	new	X	X		7/13/2021	TBD	SA
UW	TAPPS	new	X			8/4/2021	TBD	SA

GNSS co-locations

New seismic and geodetic co-locations have been deployed, continuing on with joint PNSN and UNAVCO efforts that began in 2017. During the performance period, 13 new seismic stations were directly co-located at existing GNSS stations, 5 in Oregon and 8 in Washington. In addition, 3 new GNSS stations were directly co-located with existing seismic stations in the central Oregon Coast Range by UNAVCO.

2.3.2.2 Maintenance/repair sites NOT funded by ANSS or VHP

As ShakeAlert has driven the growth of PNSN seismic station counts beyond those that compose our core ANSS sites, our duty to maintain and operate new stations is supported directly by ShakeAlert funds. Upkeep of stations installed in the past 5+ years requires attention in the field and data center, including field repair and upkeep, remote monitoring and assurance of data flow and firmware upgrades, all of which has consumed staff time and travel resources. Adherence to such maintenance competes with parallel efforts to build out the network, and this competing time commitment remains a challenge for the upcoming project period.

2.3.2.3 Telemetry improvements

Telemetry hubs (e.g., NoaNet Radar Hill/Holy Cross, "OlympicNet", UOcampus)

PNSN continues to further utilize (and deploy new) telemetry hubs in the region. Two SW Washington connections to the regional Northwest Open Access Network (NoaNet) operated by a non-profit (https://www.noanet.net/) are achieving high-reliability backhaul for 8+ stations. Two mountaintop towers receive data from the remote stations, which are then telemetered back to UW via NoaNet fiber links. A strategically-placed new Rohn tower installation on the far NW Olympic peninsula now serves as a local hub for 4 stations, including multiple data routes back to UW. In Oregon, the UO campus receive node gathers two high-bandwidth wireless links, each of which gather multi-hop networks in the central Coast Range and western Cascades, respectively. New stations and/or repeater nodes are allowing for additional inclusion into this network topology as well as alternate data pathways. Two Coast Range locations serve as collection hubs that have terminal data pathways via Oregon's Department of Transportation (ODOT) digital microwave network. Each site gathers 3 seismic stations, and aligns with growing geographic topology that distributes usage of the highly-reliable ODOT network.

Telemetry improvements; As the PNSN network is building out, we continue to increase the diversity of telemetry modes, hardening of local devices, and strategic placement of new stations. Balancing of modes focused on reduction of cellular network usage, reduction of "weak-LAN" connections, and greater use of high-reliability networks as described above. Figure 2.2.1.2 summarizes the balance of our current data backhauls. Hardening of devices was achieved by installing backup power systems for radio and network devices or implementation of VPN devices to establish more reliable connections to the data center. Increasing use of high-reliability networks was achieved by deploying more links to the hubs mentioned above or links to hosted networks that demonstrate diligent practices (e.g., K-20 higher-education institutions). Additional efforts included obtaining UO- and UW-subscribed cellular service through the AT&T FirstNet platform, a service that offers protected traffic and more robust service.

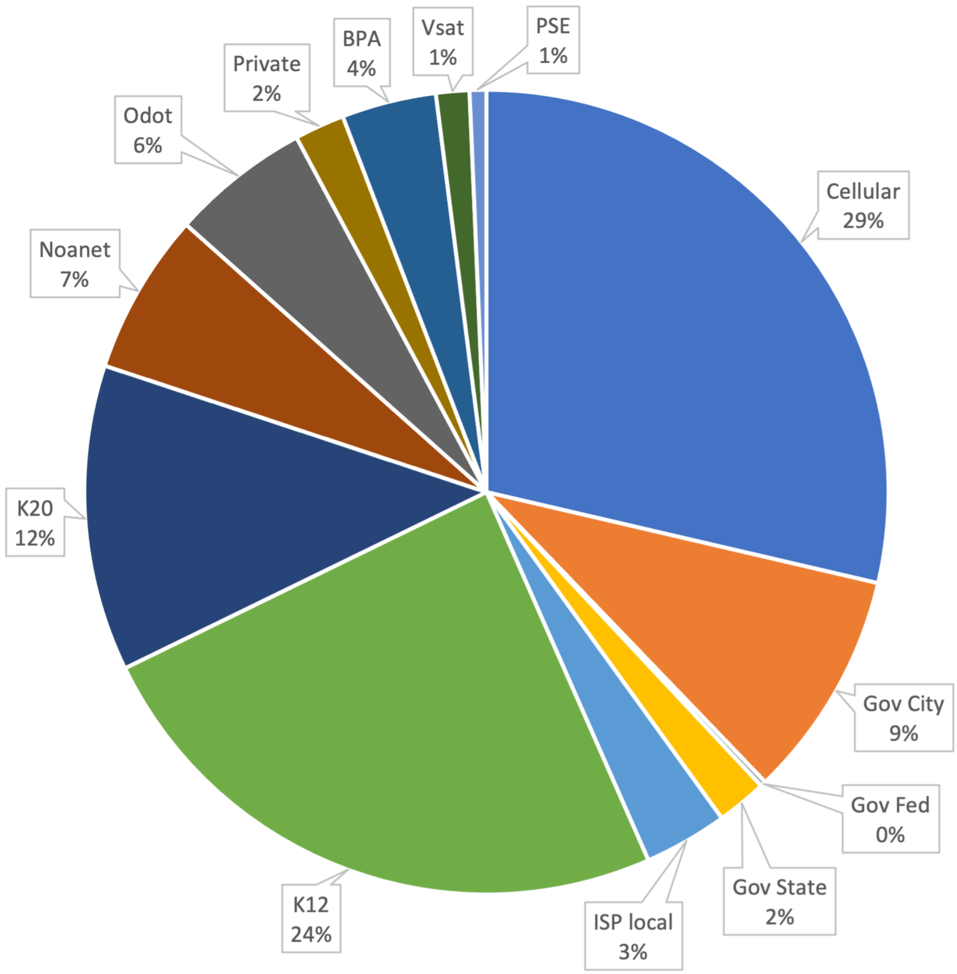

Figure 2.3.2.2. *Pie chart showing the diversity of data pathways back to the UW or UO as of September 2021. K12 and K20 are school networks, NoaNet stands for Northwest Open Access Network, described in the text. Odot is the Oregon Department of Transportation. BPA stands for the Bonneville Power Administration, and PSE for Puget Sound Energy. The other categories are self-explanatory.*

2.3.3 University of Washington sole activities related to Task 2

2.3.3.1 Establishment of contracts and working with contractors

For this two-year period of high-volume build-out we established several contracts. We hired two different contractors to do environmental assessments that conformed to the National Environmental Protection Act (NEPA) standards for each proposed new site as well as existing sites that were to be significantly altered. These NEPA reports were then submitted to the USGS to be signed to obtain the NEPA permit for each site. We commissioned SunWize Power & Battery LLC to construct the electronics enclosures, including electronics control panels, for our sites, and this required detailed drawings as well as a few adjustments. Prior to this collaborative agreement, the PNSN had no experience hiring an external company to prepare sites and install seismic equipment, however, it was the only feasible way to construct the number of sites desired. We were able to justify the build-out of the network as a capital project to the University, however, it took quite some effort to figure out how to make this happen within the State and University bureaucracy. Contracting out the work meant having to write very detailed siting reports (exhibits) for the contractor to use. Our siters and technicians were in charge of planning and designing the telemetry connections and established the networking connection to get the data back to the UW. These are very time consuming tasks and despite having hired contractors, our own crew was kept very busy. Once we figured out the workflow and separation of responsibilities, working with the contractor (Hasting Micro-Seismic Consulting; HMSC, Inc.) was very successful. Despite the pandemic we were able to deliver over 150 new sites for ShakeAlert.

2.3.3.2 Other synergistic activities

PNSN staff at UW is working together with Washington Department of Transportation (WSDOT) staff to create a so-called interlocal agreement that will provide the foundation for the PNSN to be able to install equipment on WSDOT properties throughout the state. This agreement is not in place yet, however, we anticipate that it will allow us to more easily site stations, as well as data relay sites. A similar agreement is in the works with the WA Department of Natural Resources (DNR). The PNSN@UW monitors the Hanford Site for the Department of Energy under a sub-contract with Hanford Mission Integration Solutions (HMIS). Under this contract, we have been able to modernize many sites in Eastern WA, most of which now contribute to ShakeAlert as well. A few of the broadband-only sites that we maintain for the USGS Volcano Hazards Program also contribute data to ShakeAlert.

2.3.4 University of Oregon sole activities related to Task 2

2.3.4.1 Leveraging multi-hazards mission

In parallel with ShakeAlert activities, UO also cooperates with external partners to deploy additional real-time monitoring stations and/or sensors. By motivating funding requests and/or partnerships that offer shared-resources, we are having increased success in accessing data transport, power supply, and vertical structure assets. Examples:

- BLM, Vale/Burns/Lakeview Districts: BLM has sponsored AlertWildfire camera locations, including ground-disturbance considerations and contributed communications tower space. Two seismic stations relay through these sites, allowing for a shared backhaul. In one instance (UO.JAZZ), the last mile 900 MHz link allows for a lower-latency link when comparing use of a cell modem onsite

- Clackamas 800 Radio Group: In the greater Portland Metro area, C800 operates a multi-county, multi-user microwave network. They donate tower space, power usage, and data backhaul to their data center because they value the fire monitoring effort. Seismic data from 1 site is also gathered, and many additional sites are under planning.

- ODOT Wireless: We have developed a second agreement with the State that allows for installation of high-bandwidth radios and antennas. A separate agreement (the original offers low-bandwidth antennas AND transport across the State microwave network) allows us to gather data from remote camera sites and repeat wireless links to available internet locations. Within this approach, we now transport seismic data and either hand off to State microwave or backhaul with camera data to final transport. In such cases, we can remove individual seismic stations off of cellular modems or other stand-alone modes of backhaul.

2.3.4.2 Growth of Data Operations and Equipment Operations

As funded under this cooperative agreement, UO was able to hire a full time systems and networking administrator, Mats White. Prior to this hire, our lead field tech (Meyer) and co-PI (O'Driscoll) were tasked with handling IT networking matters. Issues that exceeded our capability required support from UW or USGS-Seattle staff. Prior to substantial growth of the monitoring network in Oregon, reliance on UW/Seattle was not a major ask of their staff. However, now that the number of operating stations in WA and OR has grown, it is imperative that UO has stand-alone operations regarding IT networking and related data collection. With the hire of Mats White, UO now has a primary lead to handle ongoing monitoring and response to network related matters. In addition, he has worked closely with the University of Oregon Information Services department to develop a generalized internal IP address space that will integrate Virtual Routing Function hosted-traffic with an emerging statewide fiber infrastructure build (LinkOregon). Mr. White has also assumed the lead of coordinating and cooperating with PNSN headquarters in Seattle.

In addition to Mats' hire, additional training of a part-time assistant sysadmin took place due to delay in original hire and subsequent carryover of year 1 funds into year 2. The assistant role allowed for support of routine tasks in concurrence with Mats' efforts. The assistant is also employed as a part-time field technician, and supports seismic equipment and data device preparation.

In the realm of equipment testing, preparation, and remote troubleshooting, Dr. Gillean Arnoux has assumed the lead for UO. Arnoux has also trained a few staff members to execute tilt-testing and basic earthworm operation.

2.3.4.3 UO Programmatic Structure: UO has installed layers of supervisory structure to better facilitate operational workflow and programmatic feedback and communication. Sara Meyer is now the UO field lead, and Gillean Arnoux is the UO Assistant Network Operator. Both positions are charged with supervision of 3-4 staff. As a result, co-PI O'Driscoll now had a reduced direct report list of 5 (prior to reorganization it was over 10 staff). We cover 3 weekly meeting to discuss program matters across our group structure; Management (Program and Business), Department/Team Operations (i.e., middle-management), Full-group meetings.

UO has subscribed to the Atlassian workflow software, including modules that track meeting notes, tasks, projects, and allocation/tracking of time. Configuring the software and tailoring it to the needs of our program has required dedication from a few UO staff members. Now that we have a functional version of the software, and a defined relationship to other software platforms hosted by UW, we are achieving the goal of presenting group information in a shared platform. Such information sharing is critical for scheduling, inventory, communication of program deliverables and expectations, and more.